PHYSIOLOGY OF GROWTH IN APPLE FRUITS

Between-site variation in cell physiology and disorder incidence

by

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This thesis embodies the results of original research work carried out by the author during the years 1954 to 1956 inclusive. It has not been submitted previously for any other degree. Assistance with the laboratory work is acknowledged in the text.

The two papers whose titles are given below are included at the end of this thesis as supporting material. All the laboratory work and a substantial part of the field work was carried out either by the author or under his supervision.

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The Physiology of Growth in Apple Fruits.

III. Cell characteristics and respiratory activity of light and heavy crop fruits. D. Martin and T. L. Lewis.

VII. Between-tree variation in cell physiology in relation to disorder incidence. D. Martin, T. L. Lewis, and J. Cerny.

These two articles have been removed for copyright reasons however the cover pages for them have been kept for citation purposes and are located on pages 96 and 97

CONTENTS

INTRODUCTION

In recent years studies have been made of the variation in the physiology and disorder incidence of apples within a tree and between trees in one orchard, within a season and between seasons. One of the remaining problems is that of between-site variation.

The existence of between-site variation is traditional, and is regarded by orchardists as considerable even when cultural treatments do not differ. For example, the fruit of the Braeside area in Southern Tasmania grown at an altitude of about 700 feet is reputed to be of superior keeping quality to that grown at the general level of the Huon Valley.

Certain patterns of between-tree variation have now been established (Martin and Lewis 1952, Martin 1954a,b) which enable us to take account of some variables when making a between-site comparison. This thesis describes an attempt at such a comparison. It embodies investigations carried out in the period 1954-1956, using small plots on different sites in three localities in the Huon district of Tasmania, with a view to finding answers to the following questions:

(1) Do differences between sites depart significantly from the normal between-tree variation?

(2) Does fruit from high and low altitudes differ in its susceptibility to disorders?

(3) If there are any site or altitude differences in disorder susceptibility are they accompanied by significant differences in the physiological

characteristics of the fruit? If so, do these differences tend to confirm or deny theories developed from the between-tree studies?

(4) Are there any differences in the between-site variation between seasons, and if so how far are they in line with indications from the ideas developed from other studies?

REVIEW OF THE LITERATURE

The growth and subsequent storage behaviour of an apple are the result of the complex interaction of a number of different factors. Variation between fruits of the same variety grown on different sites is due to between-site differences in one or more of these factors.

Although studies aimed at the evaluation of these factors have been in progress for more than half a century, no comprehensive survey appears to have been published of the large amount of literature that has emerged from these investigations. Wallace (1930), however, has presented a classification of the various orchard factors followed by a brief outline of some of the more important conclusions which have been drawn from the studies in this field.

A great deal of confusion has arisen in the past when writers have neglected to give a detailed description of the disorder under discussion, because what is essentially one disorder may manifest itself in a somewhat different manner in different varieties, and consequently become called by different names.

In this review the disorders are named according to the classification of Carne (1948). The term "breakdown" will be used as a general name for the group of disorders of which low temperature breakdown is the most important and probably the type usually referred to as "breakdown" in the literature.

While every effort has been made to identify the disorders referred to in the literature from their descriptions, these are in some cases so inadequate as to render some inaccuracies inevitable.

The various factors responsible for between-site variation are considered under the following main headings, as suggested by Wallace (1930):

(1) MATERIALS:
  (a) Rootstocks.
  (b) Tree age.
  (c) Red bud sports.

(2) ENVIRONMENTAL FACTORS:
  (a) Natural:
    (i) Climatic factors - rainfall, temperature, sunlight.
    (ii) Soil factors - physical and chemical properties.
  (b) Artificial:
    (i) Cultural and manurial treatments of the soil.
    (ii) Manual operations upon the tree such as pruning, thinning, and ring-barking.
    (iii) Time of picking.
    (iv) Delay between harvesting and cool-storing.

(3) FRUIT SIZE AND CROP SIZE.

Because it is not always easy to consider the factors separately due to the different ways in which they may interact, the above scheme of classification is not rigorously adhered to in this review.

The effects of the use of chemical sprays for thinning, for increasing fruit colour and for preventing pre-harvest fruit drop have not been considered as the investigations of these effects are still in the preliminary stages.

(1) MATERIALS

(a) Rootstocks:

Kemmer (1943) stresses the importance of the rootstock as a locality factor on the ground that it is the medium through which a number of environmental factors exert their influence upon the fruit. Storage differences due to different rootstocks may not occur under all circumstances, but under certain environmental conditions there may be pronounced influences (Wallace 1930). Kidd and West (1933, 7, 8) found little difference due to rootstocks in the susceptibility of fruit to breakdown or rotting, and Padfield (1949a) observed that different rootstocks and intermediate scion varieties showed no consistent effect on the incidence of core flush in Granny Smith. Top-grafting on a vigorous stock was shown by Palmer (1931) to favour the incidence of breakdown in Jonathan.

Superior storage behaviour of fruit grown on

seedling stock has been reported by Breviglieri (1948) with Peasgood, Rome Beauty, Delicious and Jonathan growing in Palestine, and by Tiller (1929), who found that Jonathan fruit grown on seedling stocks developed less than half the amount of severe breakdown showing in fruit grown on other stocks.

(b) Age of tree:

The difficulties in the interpretation of storage data from age of tree experiments are described by Wallace (1930), who shows that any results obtained may be the effects of differences in cropping and pruning. He has found that the differences in susceptibility to disorders are of the same kind as would be expected from such factors. Padfield (1954) states that apples from young trees behave like fruit from light crops. Smith (1926) indicated the need for determining whether tree age and crop size have an effect on bitter pit when apples of the same size are compared. In view of more recent findings (Martin 1954a,b), it would seem necessary rather to compare apples from trees bearing fruit of the same mean size.

Overholser et al. (1923) found that breakdown in Yellow Newtown occurred more in fruit from old trees and thought that it was probably the effect of a difference in the maturity of the fruit.

(c) Red sports:

Clarke (1952) compared the storage behaviour of apples of the varieties Northern Spy, Jonathan, Rome Beauty, Stayman Winesap and Delicious, with that of the fruit of some

of their corresponding red sports. In all but the first named variety fruit of the standard variety showed superior keeping quality, but differences did not become apparent until late in the storage season. In a comparison of superficial scald incidence in Rome Beauty and its red sport Frimley Beauty, Padfield (1955) found that the standard variety generally developed less scald in storage.

(2) ENVIRONMENTAL FACTORS

(a) Natural:

(i) Climatic factors - Effects of climate on bud development, flowering and fruit development.

Air temperature appears to be the predominant climatic factor affecting bud development, time and duration of flowering, and the setting and subsequent development of the fruit.

DeVilliers (1947) considers that the chilling requirements for normal bud development of the average apple variety are a mean temperature less than 48°F for at least two months.

Temperature sum and rainfall are considered by Schaer (1946) to be the only climatic factors affecting time of flowering in apple trees, while Sisler and Overholser (1943) showed that in Delicious air temperature alone appeared to have any effect. Weger (1944) found air temperature to determine both the beginning and the progress of the blossoming period. In 120 apple varieties studied by Brown (1940), differences in temperature in early March affected flowering time more than did later differences.

Heavier fruit setting has been found to result from a greater number of day degrees for the seven day period following full bloom (Gardner et al. 1949).

Osterwalder (1949) found that the quality and rate of maturation of pome fruits were not affected by the period of insolation but were determined only by temperature. Rate of growth and maturation were determined not only by the temperature sum but also by the temperature distribution throughout the season. In varieties maturing in August and September the date of harvesting is most influenced by May and June temperatures, according to Berggren (1947). For those maturing in October, the date of harvesting is most influenced by August and September temperatures. On the other hand, Haller and Smith (1950) found the period required to attain maturity from full blossoming to be fairly uniform for a given variety under widely different climatic conditions.

Effects of orchard temperatures during the growing season.

Low orchard temperatures during the growing season have been shown to favour the incidence of brown core in McIntosh (Smith 1942, Smock 1953). Carne and Martin (1935) have shown that susceptibility to breakdown in a number of varieties grown in Tasmania is greater the lower the average temperature in the last four to eight weeks prior to harvest. Yellow Newtown is also rendered more susceptible to breakdown. Overholser et al.(1923) were able to increase breakdown susceptibility in this variety by lowering the mean orchard temperature by 5° F during the growing months, and to reduce

susceptibility by raising the mean orchard temperature by 10°F during the same period.

Good keeping quality has been found to be associated with warm dry weather during the few weeks preceding picking in the varieties Bramley's Seedling (West 1930), Delicious (Fisher 1943) and Cortland (Savage 1941). Plagge and Maney (1937) thought that apples were generally rendered more resistant to deep scald by hot dry seasons. On the other hand, susceptibility to superficial scald has been found to be associated with high temperatures during the latter part of the growing season in Rhode Island Greening (Smock 1953) and McIntosh (Uota 1952, Smock 1953). Brooks and Fisher (1926) considered that high temperatures were more important than intensive sunlight in the induction of water core.

Effects of Exposure to Sunlight.

Fruits borne in the interior of the tree where they are shaded by the leaves may differ markedly in their storage behaviour from those growing on the outside of the tree where they are exposed to the sun. This is hardly surprising in view of the temperature difference of nearly 10°C recorded by Lessler (1947) between the sunny and the shaded sides of Wealthy apples on clear days. Differences in storage behaviour between fruits from different parts of the tree are probably much less important in Tasmania where a small, open shaped tree is the general rule.

Water core has been found to occur more in fruits exposed to the sun on trees of a number of varieties (Brooks

and Fisher 1926, Padfield 1954). Crops on trees growing in situations where they are exposed to hot winds and long periods of sunlight are particularly susceptible to this disorder (Carne and Martin 1934). Exposed Bramley's Seedling fruits are more susceptible to superficial scald, always contain more dry matter, and usually have less total nitrogen but more reducing sugars, sucrose, and total sugars (Wallace 1953). Smock and Southwick (1945) found that shading limbs of Rhode Island Greening and McIntosh trees often reduced scald, while shading individual fruits seemed to increase scald. However, Harrison (1926) did not find any relation between deep scald susceptibility and the degree of exposure of the fruit.

Shaded fruit is more subject to breakdown in the Yellow Newtown (Overholser et al. 1923), and Cox fruits in the interior of the tree have been found to be more susceptible to bitterpit than those on the periphery (Kaiser 1924), although Wallace (1953) reports the reverse effect with regard to both bitterpit and rots in Bramley's Seedling.

Smock (1946) was able to increase the susceptibility of McIntosh fruits to brown core by the shading of individual limbs during the growing season.

Effects of Rainfall and Irrigation.

Heavy rains and heavy irrigation are generally thought to force the growth of the fruit and thus render it less resistant to various storage disorders. The overall effects of these two factors may not be identical because heavy rainfall is generally accompanied by lower orchard

temperatures and a lower aggregate of hours of sunshine.

Heavy rain or heavy irrigation towards the end of the growing season has been found to increase the incidence of breakdown in Jonathan (Palmer 1931). Wet seasons are also considered to favour the incidence of deep scald (Padfield 1954) and of rots (Wallace 1946). In McIntosh severe core flush has occurred in years of high rainfall and low temperatures during maturation, whereas light core flush years have been relatively dry ones (Smith 1942). Wallace (1953) states that heavy rainfall results in fruit with generally poor colour and with lower contents of dry matter, acid and total sugars.

Heavy irrigation towards the end of the growing season has been reported to favour the incidence of bitterpit in fruit of the Gano, Grimes and Jonathan varieties (Brooks and Fisher 1918), and many other workers consider bitterpit incidence to be closely related to soil moisture conditions. However, experiments with Cox in New Zealand have shown that irrigation has little, if any, effect on bitterpit or breakdown in this variety (Padfield 1954). Increased susceptibility of Grimes apples to superficial scald (Brooks et al. 1919) and of Rome Beauty and Delicious apples to superficial scald and breakdown (Haller and Harding 1937) has been reported. Irrigation reduces the susceptibility of Winesap, Yellow Newtown and King David apples to watercore (Brooks and Fisher 1926). No consistent effect of irrigation upon susceptibility to Jonathan Spot has been found (Brooks and Fisher 1918, Plagge and Maney 1924).

In Palestine, better keeping fruit was obtained from trees definitely profiting by irrigation at a late stage than from trees deprived of irrigation at an early stage (Breviglieri 1948). Veihmeyer and Hendrickson (1950) claim that the idea that the quality of irrigated fruit is lower than that of non-irrigated has been found to be erroneous.

Both rainfall and irrigation are very potent factors influencing the mean size of the fruit on the tree, which of recent years has been shown by Martin (1954a) to be the most important single index in determining the susceptibility of the fruit to certain disorders. In very little of the published work cited above has any check been made upon mean fruit size per tree. In some cases where it was observed that trees in irrigated plots had a greater number of large fruits, fruit size was erroneously eliminated as a factor responsible for the observed increase in disorder incidence on the grounds that small as well as large fruits were affected by disorders which usually affected only the larger fruits of a tree. From these considerations it seems likely that many of the reported findings of increased susceptibility to disorders resulting from heavy rains or heavy irrigation during the late growing season might be explained on the basis of an increase in the mean fruit size per tree brought about by these factors.

Other observations relating to climatic effects.

Wallace (1953) has found no obvious correlation between seasonal weather conditions and rots and breakdown developed during storage in apples stored in a sound condition.

Similarly West (1929) reports no obvious correlation between weather during the complete growing season and the storage life of Bramley's Seedling apples. Climatic effects were thought by Tiller (1929) to be intimately bound up with the occurrence of Jonathan Spot, as it occurs on soils of widely different types. Plagge and Maney (1924) found a slight relationship between the amount of sunlight during the growing season and the incidence of Jonathan Spot. With Edward VII apples, a correlation has been found to exist between the amounts of sunshine and rainfall during the latter part of August and the early part of September and the subsequent development of superficial scald six months after picking. Scald is most severe after long periods of sunshine. A linear relationship has been shown between scald incidence and the difference between evaporation of water and rainfall (Anon. 1954).

In the Southern Tyrol, the keeping quality of apples grown at Vintschgau (altitude 500-700 m.) is claimed to be superior to that of apples produced lower down at Merano (Kessler 1946). Fruit of the varieties Rome Beauty, Peasgood, Delicious and Jonathan grown in the mountains of Palestine was shown to have superior keeping quality to that grown on the plains, which in turn kept better than apples grown at sea-level (Breviglieri 1948). Differences in chemical composition between mountain and plains fruit of the varieties Red Astrachan, Peasgood, Delicious and Rome Beauty in Palestine were attributed by Damast (1949) to differences in temperature and in the intensity and quality of the light.

(ii) The Influence of Soil Type

Little has been published as to the part played by the physical nature of the soil in the development and subsequent storage behaviour of apples.

Wilcox (1945) considered that the heavier and deeper the soil, the higher was the pH, the more vigorous were the trees, the less was the degree of biennial bearing, the higher was the total yield, and the higher was the yield of high quality fruit.

From the little evidence available it would appear that resistance to bitterpit and breakdown is greater in fruit grown on light soils. In the Nelson district of New Zealand fruit from fertile light loam has been found to be more resistant to breakdown than fruit from the poorer sandy loams. (Tiller 1930). Palmer (1931) has reported that breakdown in Jonathan apples is favoured by heavy, moisture-retaining soils. Tiller and Chittenden (1933) showed that Cox apples grown on fertile light loam were much less susceptible to bitterpit than fruit of the same variety grown on clay loam deficient in nutriment. On the other hand, Grimes apples grown on a heavy clay soil developed considerably less superficial scald than fruit grown on a heavily fertilized sandy soil (Brooks et al. 1919).

(b) Artificial

(i) Soil Treatments and the Chemical Composition of the Fruit

Nitrogen Fertilization and Grass Treatment

Reyneke and Eksteen (1934) state that apples

containing large amounts of nitrogen or apples from trees on moist and nitrogen-rich soils are more susceptible to bitterpit. This view is supported by the work of Kaiser (1924) with Cox.

Susceptibility to rots is favoured by soil applications of nitrogenous fertilizers in Cox (Rigg and Chittenden 1937), Fameuse and McIntosh (Davis and Blair 1936).

Breakdown incidence has been found to be increased by nitrogen applications in Cox (Rigg and Chittenden 1937) and in Yellow Newtown in light crops from vigorous trees (Ballard et al. 1922). On the other hand Gourley and Hopkins (1929) found that heavy applications of nitrogen did not induce breakdown in apples of the varieties Wealthy, Stayman Winesap, Grimes, Jonathan or McIntosh.

Plagge (1930) showed that nitrogen applications resulted in increased susceptibility to deep scald in Jonathan and Grimes compared with fruit from nitrogen-deficient trees.

While Gourley and Hopkins (1931) found that nitrogen applications increased susceptibility to superficial scald in Grimes, Jonathan and Stayman Winesap, Savage (1941) has reported less scald on Cortland apples with high nitrogen levels. Degman and Weinberger (1934) found no consistent effect from year to year of nitrogen additions on scald in Stayman Winesap and York Imperial. Smock and Southwick (1945) have shown that high nitrogen levels do not increase scald incidence in Rhode Island Greening or McIntosh.

Nitrate applications have been shown to result in less watercore in Yellow Newtown and King David fruits (Brooks

and Fisher 1926).

Plagge and Maney (1924) were unable to find any effect of soil nitrogen treatment upon the incidence of Jonathan Spot.

Lagassé (1930) reported that nitrogen applications as great as 20 pounds of Sodium nitrate per tree had no influence upon the keeping quality of Yellow Transparent apples.

Delayed maturity, increase in fruit size, and decrease in colour resulted from nitrogen applications with Cortland apples (Eaves 1953). Weeks et al. (1952) found that McIntosh trees with a high nitrogen level had the softest fruits whereas low nitrogen trees had the hardest fruits.

Wallace (1930, 1953) has shown that growing fruit trees under grass results in a big decrease in the nitrogen content of the fruit, reduced ripening rate and breakdown incidence, and consequently a longer storage life. However, grass treatment in combination with nitrogen applications may give more rots than clean cultivation alone (Wallace 1946). In soil treatment experiments with Grimes Golden, the slight decrease in scald incidence usually noticeable with growing trees under blue grass was attributed to earlier maturity of the fruit (Plagge and Maney 1924).

Hulme (1956) has shown that the total and protein nitrogen contents of Cox fruit are increased by ammonium sulphate manuring, and further increased by additional potassium sulphate manuring. The nitrogen content is lower

from trees on grassed down than from trees on cultivated plots. Total nitrogen contents vary widely between trees in one orchard receiving different treatments, and between trees in different orchards.

Potassium and Phosphorus Treatments

Although Brown (1929) associated good keeping quality with high percentages of available potash and phosphate in the soil, and of potash and phosphate in the fruits of Bramley's Seedling and Worcester Pearmain, there is scanty evidence in the literature to support such a view, apart from the finding by Brooks and Fisher (1926) that fruit from potash-treated King David trees showed less watercore. Wallace (1934) states that high potash fruits from vigorous trees have always shown more bitterpit than fruits from trees deficient in potash. Moreover, although potassium-deficient fruits of the varieties Grenadier and Bismarck were found to be more susceptible to breakdown and invariably wilted badly in storage, they developed fewer rots and had a longer senescence period (Wallace 1930, 1946). In a manurial experiment with Cox, Kidd and West (1937) found that the fruits from the treatments including potash were susceptible to scald, the susceptibility being greatly increased by the addition of phosphorus. On the other hand, Weinberger (1934) did not find any consistent difference in scald incidence in fruits from potassium-treated and control trees of the varieties Stayman Winesap, Rome Beauty and York Imperial.

Eaves and Leefe (1955) have shown that fruit from

Cortland trees receiving potassium had a higher acid content than that of apples from untreated or nitrogen-treated plots.

Boron Treatments

Borax treatments have greatly increased the incidence of breakdown in Jonathan, while scald has been appreciably reduced in Grimes Golden, Delicious, Rome Beauty and York Imperial, (Haller and Batjer 1946). These effects are attributed to advanced maturity resulting from the treatment. Martin and Carne (1950) have shown that, in the absence of any boron deficiency symptoms, boron applications reduced fruit size and the incidence of bitterpit in Cleopatra.

General

Fertilizer treatment was found to have no significant influence upon the incidence of breakdown or the rate of softening of Jonathan apples (Magness and Overley 1929), while Trout et al. (1940) concluded that differences in wastage in apples of this variety between districts could not be attributed to differences in any chemical constituent.

Although Wallace (1930) considered that storage qualities of apples were not related simply to the content of total nitrogen, titratable acidity, sugars or mineral constituents, he did associate poor keeping quality with high sucrose content, and superior quality with low nitrogen content. Haynes (1925) has stated that high acidity and a slow rate of acid loss favour breakdown. On the other hand, Plagge and Gerhardt (1930) considered breakdown to be due to

a slow rate of acid loss which is associated with low initial acidity.

Damast (1949) has reported that mountain fruit in Palestine has more dry matter, sugar, cellulose, acid and ash, and less protein than fruit grown on the plains. He attributes the better keeping quality of the mountain fruit to their greater reserves of respirable substrate and low rate of respiration needed to supply energy for the maintenance of the smaller amount of protein. On the other hand, Manaresi and Capucci (1941) found that in Italy differences in chemical composition bore no definite relation to the latitude or altitude of the place of growth, and that the same varieties grown in different parts of Italy were of approximately the same composition.

(ii) Effects of Pruning, Thinning and Bark-ringing

Hard pruning tends to increase the exposure of the fruits to direct sunlight, and results in increased fruit size, colour and sucrose content (Wallace 1953). It has been shown to favour the development of breakdown in Jonathan (Palmer 1931), and of bitterpit in Cox (Kaiser 1924).

Severe thinning also results in larger fruits and its effects on keeping quality are similar to those of hard pruning. Breakdown susceptibility is increased in Bramley's Seedling (Wallace 1953) and Jonathan (Palmer 1931). Wallace (1930) indicated that scald susceptibility might also be increased, but found no effect on rot incidence (1946). Fruit thinning in Early Victoria to one fruit per truss has

not affected susceptibility to bitterpit, but removal of 50% of the blossom trusses has been associated with a high percentage of bitterpit (Wallace 1934).

In bark-ringing experiments on Bramley's Seedling and Newton Wonder, Wallace (1953) found that fruit from ringed trees proved highly susceptible to scald and breakdown, and that fruit liable to develop core-flush tended to develop breakdown rather than core-flush. No consistent effect of ringing upon bitterpit was found, although it has sometimes produced tree pit in hot dry years. Ringing decreased the nitrogen content of the fruit and increased the total sugars content. An increase due to ringing in susceptibility to breakdown has also been demonstrated in the Yellow Newtown by Ballard et al. (1922).

(iii) Effects of Degree of Maturity at Picking

The degree of maturity of the fruit at the time it is picked may in many cases exert a marked effect upon its susceptibility to disorders in subsequent cool storage.

Picking the fruit in an immature condition generally results in shrivelling because the lenticels have not been corked over and the waxy bloom has not developed (Reyneke and Pearse 1943, Wallace 1953). It also favours the incidence of deep scald in Jonathan (Plagge and Maney 1924, Tiller and Chittenden 1933), although Plagge and Maney (1937) showed that the effect of maturity on deep scald susceptibility was not always in the same direction for different varieties, and that in one variety the direction might change between seasons.

Increased susceptibility to superficial scald resulting from early picking has been demonstrated for the varieties Granny Smith (Padfield 1949), Grimes (Brooks et al. 1919, Plagge and Maney 1924), Cortland (Savage 1941, Christopher 1941, Smock and Southwick 1945), Rhode Island Greening (Christopher 1941, Smock and Southwick 1945), Rome Beauty (Brooks et al. 1919, Comin and Ting 1951, Padfield 1955), Stayman Winesap, Baldwin and Bellflower (Brooks et al. 1919).

Although early picking has in some years reduced the incidence of bitterpit in Bramley's Seedling (Wallace 1953) and Cleopatra (Tiller and Chittenden 1933), it has been found to increase bitterpit susceptibility in a number of varieties, including Jonathan (Brooks and Fisher 1918), Gravenstein (Allen 1931), Cleopatra (Wickens and Carne 1927), Cox and Ribston Pippin (Smith 1926), Granny Smith (Tindale and Huelin 1943), Newtown and Northern Spy (Britton et al. 1943).

Picking at a later stage than that generally considered normal favours the incidence of a number of disorders. Trout et al. (1940) found increased deep scald incidence in Jonathan, while an increase in susceptibility to breakdown has been demonstrated in fruit of the varieties Yellow Newtown (Overholser et al. 1923), Bramley's Seedling (Wallace 1953), Grimes (Plagge and Maney 1924), Cox (Britton et al. 1943) and Jonathan (Palmer 1930, Trout et al. 1940). In studies with Jonathan, King David and Winesap apples, Brooks and Fisher (1926) found that watercore incidence rose rapidly as the fruit became overmature on the tree. Fungal

rotting in Bramley's Seedling is favoured by delayed picking (Wallace 1953) and so is Jonathan Spot (Plagge and Maney 1924, Tiller 1929), although Trout et al. (1940) state that it sometimes occurs on immature fruits. On the other hand, Smock (1946) has found reduced susceptibility to brown core in McIntosh resulting from late picking, and Britton et al. (1943) have reported similarly for Newtown.

One important consideration which has been overlooked in practically all studies on maturity effects on storage behaviour is the increase in the mean size of the fruit on a tree accompanying any delay in harvesting the fruit. Under favourable growing conditions this increase in size may be quite considerable, even over a period of a few days. Mean fruit size per tree has been shown by Martin (1954a,b) to be the most important single index in determining the susceptibility of Cox, Jonathan and Cleopatra fruits to bitterpit and breakdown, breakdown and deep scald, and bitterpit, respectively. It seems not unreasonable to suppose that this may also be the case with some other varieties relative to these and possibly some other disorders. In view of this it seems probable that in some cases at least in which increased susceptibility to storage disorders has been observed in late picked fruit, the increase in mean fruit size per tree occurring during the delay period may be partly or perhaps even wholly responsible.

(iv) Effects of Delayed Storage

Withholding apples from cool storage for a period of a few days to several weeks after harvest may exert a

marked effect on the susceptibility of the fruit to certain storage disorders. This effect may vary widely with different varieties and with the temperature at which the fruit is held during the delay period.

The incidence of deep scald in Jonathan was found to be increased by pre-storage delay for one week at 75°F. (Brooks et al. 1920). Plagge and Maney (1937), however, showed that prompt storing frequently caused Jonathan, and usually Northwestern Greening, to be more susceptible to this disorder, but usually increased resistance in Grimes Golden, Wealthy and Golden Delicious. With a delay of five to ten weeks at 50°F. Jonathan, Grimes Golden, Winter Banana and Northwestern Greening exhibited marked resistance to deep scald, and Golden Delicious, while developing more deep scald than the other varieties, also tended to be resistant.

Susceptibility to superficial scald may be reduced by pre-storage delay in mature Grimes (Plagge and Maney 1924) and in Rhode Island Greening (Smock and Southwick 1945). Padfield (1949b) reported the same effect in Granny Smith apples but considered that delay in storage was not a practical means of controlling superficial scald in this variety, partly because of the excessive yellowing induced by such treatment. He has subsequently shown (1955) that two weeks' delay before cool storage greatly increases the susceptibility of Rome Beauty and its red sport Frimley Beauty to superficial scald.

Increased bitterpit incidence following delayed storage has been reported in Cleopatra (Smith 1926, Wickens

and Carne 1927), Cox (Smith 1926, Britten et al. 1943), Rhode Island Greening (Smock and Southwick 1945), Granny Smith (Tindale and Huelin 1943) and Newtown (Britton et al. 1943). A sharp rise in the incidence of storage disorders follows delay in the storage of Sturmer apples (Padfield 1953).

Although Plagge and Maney (1924) found that Jonathan Spot incidence increased in proportion to the length of the delay period, Tiller (1929) found the increase to be very small compared with that produced by late picking.

Trout et al. (1940) found that there was no increase in the incidence of rots in Jonathan apples subjected to delay before storage.

The disorders core-flush and senescent breakdown in Granny Smith have been effectively controlled by withholding the fruit from cool storage for six weeks (Padfield 1950).

(3) EFFECTS OF FRUIT SIZE AND CROP SIZE

In general, apples from trees bearing light crops are larger, and show an increased susceptibility to most disorders in storage. Their greater size has been shown to be due to greater cell size rather than to a greater number of cells per fruit (Martin and Lewis 1952). In general, they possess a higher content of titratable acids, dry matter and sucrose at maturity, and a slower rate of starch loss. Although they may exhibit greater hardness in the stages preceding maturity, they usually have a higher rate of softening once they have reached maturity.

The occurrence of breakdown is greater in light crop fruit of Yellow Newtown (Ballard et al. 1922, Overholser et al. 1923), and Jonathan (Palmer 1930, Strickland 1935), and probably in all other varieties susceptible to this disorder. Harrison (1926) was unable to find any relation between deep scald incidence and the size of the crop. Britton et al. (1943) found more bitterpit in fruit from light crop trees of the varieties Cox, Newtown and Northern Spy. Light crop fruit of a number of varieties shows a greater susceptibility to watercore (Carne and Martin 1934).

The larger fruits on a tree are usually more susceptible to storage disorders than smaller fruits from the same tree. This has been shown to be the case with watercore in Yellow Newtown and Winesap (Brooks and Fisher 1926); superficial scald in Cortland (Savage 1941); bitterpit in Cox (Wickens and Carne 1927, Martin 1953); Cleopatra (Carne 1928, Martin 1953) and Sturmer (Martin 1953); breakdown in Cox (Martin 1953) and Jonathan (Magness and Overley 1929, Palmer 1930, Trout et al. 1940); Jonathan Spot (Martin 1953); and deep scald in Jonathan (Trout et al. 1940, Martin 1953). On the other hand, Trout et al. (1940) considered it probable that smaller fruits were more susceptible to Jonathan Spot. Of the varieties Jonathan, Grimes, Wealthy, Golden Delicious, Winter Banana and Northwestern Greening studied by Plagge and Maney (1937), only in the last named variety were large fruits found to be more susceptible to deep scald than small fruits, and this was considered to be due to a maturity difference.

Carne and Martin (1938) found not only a positive

correlation between bitterpit incidence and fruit size within a tree, but also a positive correlation between bitterpit incidence and the average size of the fruits of different trees of the same variety growing under the same conditions. In the latter case, bitterpit incidence in fruits of the same size is greatest in those from trees having the largest average fruit size. This relation has been found to hold for the disorder breakdown in Cox and Jonathan, as well as for bitterpit in Cox and Cleopatra (Martin 1954a,b). Seasonal variation in disorder level has been found, in the final analysis, to be mainly related to differences in mean fruit size.

As mentioned elsewhere in this review, the vast majority of workers have ignored the possible influence of mean fruit size per tree on their storage results, and effects which have been attributed to maturity differences or to other orchard factors influencing the growth of the fruit may, it would appear, be in many cases traced ultimately to this factor of mean fruit size. Results of experiments described in this thesis are in full accord with this view.

EXPERIMENTAL MATERIAL AND METHODS

(1) SELECTION OF THE ORCHARDS

For the study of between-site variation, the variety Jonathan was selected, chiefly because a substantial amount of information as to between-tree and between-season variation in fruits of this variety had already been accumulated from studies in the Huon district over a number of years. Moreover, these studies were to be continued during the years 1954 to 1956, and it was hoped that they would afford a within-orchard pattern with which the between-orchard findings might be compared.

Eleven orchards situated in three different localities were selected to provide material for the investigations, six being in low-lying country in the valleys of the Huon and Mountain Rivers, and the remainder in two hilly regions several hundred feet above sea-level. All the high-altitude orchards and three of the low-altitude ones were reputed to produce Jonathan apples of consistently good keeping quality, while the remaining three low-altitude orchards had a reputation for consistently bad-keeping Jonathans. The views of cool-store operators in this regard had to be treated with caution, since the fruit of a grower who consistently picks his fruit too early or too late and cool-stores fruit of the larger sizes may be inherently of as good keeping quality as that of another grower who always picks at the correct maturity and avoids cool-storing his largest fruit.

A survey of the orchard soils was carried out in 1955 by Mr. John Loveday of the Division of Soils, C.S.I.R.O. and his findings have been reported in a Divisional Technical Memorandum. The manurial treatments received by the orchards in the years 1953 to 1956 are described in an appendix. Clean cultivation was practised in all the orchards selected. In the absence of reliable information regarding the rootstocks upon which the trees were growing it has been assumed that seedling stocks have been used in all cases, since this has always been the general practice in Southern Tasmania.

In the following description of the orchards each orchard will be assigned a number prefixed by the letters A, B or C, to denote that they are situated in the low-lying area, the Braeside area or the New Road area respectively.

Orchard A1 is in the Mountain River valley about 1½ miles N.N.E. of Huonville (altitude about 220 feet) on Huon silty loam (Taylor and Stephens 1935).

A2 is in the Huon River valley about half-way between Huonville and Franklin (altitude about 170 feet). The soil is a sandy loam considered by Loveday (1955) to approximate to the Woodbridge series as defined by Taylor and Stephens.

A3 at Ranelagh (altitude about 140 feet) is the only one of the eleven orchards which is irrigated. Although the soil was mapped by Taylor and Stephens as Huon sand, Loveday considers that it probably belongs to a different soil series.

Orchard A4 is in the Mountain River valley 1 mile N.E. of Huonville (altitude about 180 feet) on Huon sand, hardpan phase (Taylor and Stephens).

A5 is at Ranelagh (altitude about 140 feet) on Frodsley sandy loam (Loveday 1953, 1955).

A6 is in the Mountain River valley 3 miles N.E. of Huonville (altitude about 230 feet). The soil is a sandy loam on mudstone (Loveday 1955).

Orchards B1, B2 and B3 are fairly closely situated at Braeside about 2 miles S.W. of Franklin. They are at altitudes of about 630, 700 and 720 feet respectively. In all three orchards the soil is a sandy loam on dolerite (Loveday).

Orchard C1 is in the New Road district about 2 miles W. of Franklin (altitude about 870 feet). The soil is a red-brown clay loam extending deeper than $3\frac{1}{2}$ feet. The orchard is situated in a small patch of krasnozemic soil in an otherwise podzolic soil area (Loveday).

C2 is only about $\frac{1}{2}$ mile from C1 (altitude about 760 feet) but the soil is a sandy loam on dolerite (Loveday).

The orchards reputed to produce poor-keeping Jonathans were A1, A3 and A5.

(2) SAMPLING

1954 - In 1954 two trees in each of the eleven orchards were selected and numbered 1 and 2. An attempt was

made to find trees of similar growth form and vigour and bearing good crops of reasonably large fruit. At about the normal commercial picking date two samples of apples were picked from each of the trees. One sample consisted of 30 fruits $2\frac{3}{8}$" in diameter* and was used for the determination of respiration rate, cell size and chemical composition. The other sample, consisting of two standard boxes of fruit picked at random, was placed in a commercial cool store with a view to observing its storage behaviour.

The low altitude fruit was picked on March 8 with the exception of orchard A5, where the fruit was picked on March 16. The high altitude fruit, because it appeared to be later-maturing than that of locality A, was picked two weeks later on March 22. As the latter fruit still seemed rather immature at picking, two further trees numbered 3 and 4 were selected in each of the high altitude orchards, and from these samples were taken in the same manner at the end of a further two weeks on April 5.

1955 - Orchard A6 had to be omitted from the 1955 studies because of the extremely small size of its fruit. Samples were taken from pairs of trees in orchards A3 and A5 on March 15 and in all the other orchards on March 21. The difference in maturity at picking between fruit of the high and low altitude areas was not nearly so marked as in 1954.

1956 - For the 1956 studies the number of trees in each orchard was increased to four, and fruit from A6 was again included, while orchard B2 had to be omitted because of

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Footnote: The mean of the weights of individual fruits in a sample varied between 85 and 95 grams.

severe hail damage. Samples were taken from orchard A5 on March 13, from the other orchards of locality A on March 19, and from localities B and C on March 20 and 23. On April 4, a second picking was made from each of the trees in orchard A3. The fruit in all the orchards of locality B had been badly damaged by hail, and for this reason the storage samples from the remaining orchards of this area were eventually discarded after first determining the mean fruit weight. In orchard A4, trees 3 and 4 were Red Jonathans.

In each of the three years, samples were taken similarly for purposes of comparison from each of 39 trees in one plot in locality A, hereafter referred to as Plot X. All the trees are of the same age and have been receiving the same fertilizer treatment for a number of years. The dates of picking in the three years were as follows:

1954 : 16 March

1955 : 16 March

1956 : 13 March

(3) MEASUREMENT OF RESPIRATORY ACTIVITY

The respiratory activity of the fruit was estimated by measuring the rate of carbon dioxide production at a constant temperature.

After the respiration samples were picked they were brought to the laboratory in the shortest possible time and weighed before being placed in airtight tins equipped with fine bore copper inlet and outlet tubes. These tins

were immediately placed in a constant temperature room. In 1954 and 1955 a 10°C room was used, but because doubts arose as to the time taken for the temperature of the fruit in the tins to come to equilibrium a temperature of 25°C was adopted in 1956.

Hulme (1951) has shown that during the period 40 - 48 hours after picking, the rate of respiration of Bramley's Seedling apples, and presumably of apples of other varieties, does not differ appreciably from the rate at the time of picking, from about 60 days after petal fall until the onset of the climacteric.

At the beginning of this period, the push-in lids of the tins containing the fruit were placed in position and made airtight with caulking compound. Air which had been freed of carbon dioxide by passage through a three foot length of 2" diameter plastic piping filled with soda lime was drawn through the tins and over the fruit. The air from each tin was led through a large U-tube containing anhydrous calcium chloride to remove water vapour, and then through a weighed U-tube containing self-indicating granules of soda lime which absorbed the respired carbon dioxide. At intervals of 2-3 hours the airflow was interrupted and these soda lime tubes were disconnected and weighed. The increase in weight of a U-tube represented the weight of carbon dioxide given off by the sample of fruit during the interval. Respiration rate was calculated as mg. CO_2 per 10 Kg. fruit per hour at either 10° or 25°C.

This method for determining respiration rate was a modification by the author of that described by Eaves (1938), and had been used successfully in the 1952 and 1953 apple seasons.

When the method was first tested, it was found that the soda lime used to absorb the respiratory carbon dioxide released an appreciable amount of water during the absorption reaction, although it was labelled "non-deliquescent". The removal of this moisture in the air stream constituted a serious source of error in the determinations, and to prevent this a second U-tube containing anhydrous calcium chloride was used in series with the soda lime tube, the two tubes being weighed as a unit. Later, this second U-tube was dispensed with when it was found more convenient to include a small amount of calcium chloride in the soda lime tube. This precaution was subsequently dispensed with when it was found that "Sofnolite" brand soda lime did not release any moisture during the absorption reaction.

Over five seasons the method described has proved itself to be economical with regard to both equipment and the time consumed in carrying out the estimation. One person can execute measurements on as many as thirty samples simultaneously, and obtain a high degree of accuracy, provided that the removal of respired carbon dioxide from the vicinity of the fruit is taking place efficiently. In 1952 and 1953, when bell jars had been used to hold samples of 10-20 fruits, this condition had been adequately

met. However, in 1954, four gallon tins with press-in lids were used to contain the larger samples, and the excessive amount of dead air space in these containers prevented the efficient removal of the carbon dioxide by the air stream. This resulted in erratic readings in which little confidence could be placed. In the following season this difficulty was overcome by the use of smaller tins of about $2\frac{1}{2}$ gallons capacity.

(4) CELL SIZE DETERMINATION

On completion of the respiration measurements, the sample was removed from its container and the twenty most symmetrically shaped fruits were selected for the determination of mean cell size. From each apple in the equatorial plane a transverse section of the mid-cortex was cut with a razor and fixed and preserved in formalin-acetic-alcohol. The twenty sections from one sample were later stained with Ruthenium Red, which stains the pectin of the middle lamella red, and then mounted in Euparal on two slides, each holding ten sections and being thereafter designated A and B. Examination of a section stained in this way shows that the cells are roughly ellipsoidal in shape and tend to be elongated transversely with respect to the axis of the fruit.

For the estimation of cell size, a slide was placed on the mechanical stage of a microscope set in the horizontal position and equipped with an eyepiece prism, which allowed the image produced with the aid of a 100 watt projector lamp to be projected on to a sheet of white paper. The magnification was adjusted to the required value (200X)

by using a stage micrometer.

With this arrangement it is possible to measure the major and minor axes of a single cell and to determine its volume from the formula

$$V = \frac{4}{3} \pi a b^2$$

where a and b are half the lengths of the major and minor axes respectively.

The area of the surface of the cell may be calculated using these same dimensions from the formula

$$A = 2 \pi b^2 + 2 \pi \frac{ab}{e} \sin^{-1} e$$

where $e = \sqrt{1 - \frac{b^2}{a^2}}$

However, because the relationship between cell volume and cell surface area has been found to be linear over a considerable range of cell size (Martin and Lewis 1952), the regression line was used to read off approximate values for cell surface area corresponding to observed values for cell volume.

Bain and Robertson (1951) have shown that, since the cells of the cortex and pith of the apple tended to reach approximately uniform size as the fruit attained its maximum size, the average volume of the cells in the mid-cortical region could be taken as an average for the whole fruit.

A value for the mean cell volume for the sample of twenty fruits was required. To find the average size of the cells in one section of mid-cortical tissue it was

necessary to measure the major and minor axes of a number of cells taken at random. It was shown by MacIntyre (private communication) that 12 cells from each of the 20 sections of a sample would have to be measured in order to eliminate error arising from the variation in size between cells. At his suggestion, a 5cm. square was drawn in the centre of the projected field. Such a square usually enclosed the images of about four cells, and these cells were ranked 1, 2, 3 and 4 in order of increasing size. For measuring, the section was moved successively a distance equal to the diameter of the field. In each field, of the four cells in the quadrat designated 1, 2, 3 and 4, one cell was chosen by reference to a table in which these four numbers each occurred three times in a random arrangement. Twelve cells in each section were chosen for measurement in this way, using a different random arrangement of the numbers for each section.

Mean cell size was calculated separately for slides A and B of a sample, and the two values were compared in order to check the accuracy of the determinations. The agreement between the values obtained by this method for the two slides varied from good to very poor. Moreover the procedure was very slow and incurred considerable mental fatigue, which of itself was probably responsible for much of the lack of precision. Because of this it was hoped that a method might be evolved which would give consistently good agreement between pairs of slides and which would be less time-consuming and less fatiguing.

It was thought that if a point were marked on the paper in the centre of the projected field, and if the section were moved as before, a random sample might be obtained by measuring each of the cells whose outlines included the point in twelve successive fields. It was pointed out by a statistician that the use of this method would introduce a bias in favour of larger cells, as in any field projected the probability that a large cell would lie on the point would be greater than that for a smaller cell. However, it was decided that the method should be tried, and checked for any bias by comparison with the more statistically sound method. The simpler method proved far quicker and less mentally tiring than the method previously used, and the following data serve to show that good agreement could be obtained between pairs of slides with no evidence of a bias in favour of the larger cells.

SAMPLE	MACINTYRE METHOD			POINT METHOD		
	A	B	Mean	A	B	Mean
1	138	130	134	135	137	136
2	153	164	159	153	163	159
3	215	208	212	211	202	207
4	211	211	211	210	211	211
5	149	156	153	151	152	152
6	187	176	182	187	174	181
7	184	170	177	184	175	180
8	176	168	172	170	173	172
9	186	173	180	183	177	180

In view of its advantages the "point" method was adopted as standard procedure. All the 1954 determinations, which had been made by the older method, were repeated using

the "point" method, and this method was used again for the 1955 and 1956 material.

In order to determine the mean number of cells per fruit for a sample, the following formula was used

$$N = \frac{W}{\text{Sp. g. of cells} \times V}$$

where W is the mean weight of the fruits used for the cell measurements and V is the mean cell volume for these fruits. As the determination of the specific gravity of the cells would have entailed a vast amount of extra work, it was decided to adopt the value of 1.1 arrived at by Smith (1937) in his work with a number of apple varieties.

(5) ANALYTICAL METHODS

Preparation of the fruit for analysis.

After the sections had been cut for the determination of cell size, all thirty fruits of a sample were peeled thickly, and the mid-cortical tissue remaining after removal of the core was sliced and placed in a shallow weighed basket constructed of $\frac{1}{2}$" zinc-coated steel mesh. The basket with its contents was weighed and immediately placed in a tunnel drier in which the temperature was maintained between 65 and 70°C. When the material had dried to a constant weight (16-20 hours) the basket was removed from the drier and weighed quickly, its contents then being immediately transferred to a polythene bag. Later this dried material was ground with a small hand mill to a fine powder, which was stored for subsequent analysis

in a glass jar sealed with paraffin wax.

Moisture content determination.

The loss in weight of the tissue during the drying process described above was used for the calculation of the percentages of moisture and of dry matter in the fresh fruit.

Total nitrogen determination.

Total nitrogen was determined by the Kjeldahl method. A 2 gram sample of the apple powder was digested in a 250 ml. round bottom flask with about 12 ml. of concentrated sulphuric acid in the presence of a small amount of potassium sulphate which served to raise the boiling point of the acid. Selenium powder and copper sulphate were used as catalysts. The resulting digest was steam-distilled in the presence of excess sodium hydroxide in a Parnas-Wagner distillation apparatus, and the ammonia liberated was absorbed in either standard N/100 sulphuric acid or 1% boric acid solution. In 1954, N/100 sulphuric acid was used, and the amount of acid neutralized by the ammonia was determined by back-titration with N/100 sodium hydroxide using a mixed indicator composed of methyl red and methylene blue. In 1955 and 1956, however, the ammonia was distilled into about 20 ml. of 1% boric acid solution as described by Kirk (1950), and titrated directly with N/100 hydrochloric acid using the same mixed indicator. This method proved to be far more satisfactory than the former one, as accurate measurement

of the boric acid solution is unnecessary, and no error arises from any loss of the solution by splashing which may occur (before the ammonia has begun to distil over) if the initial reaction between the digest and the strong sodium hydroxide solution is very vigorous.

Protein nitrogen determination.

For the estimation of protein nitrogen a 3 gram sample of the apple powder was transferred to a small packet made by folding an 18 cm. No. 50 Whatman filter paper, and the packet was securely closed by means of sliding paper fasteners. The powder was then subjected to extraction with 75% ethanol in a Soxhlet apparatus for about 16 hours. This treatment has been shown by Hulme (1936) to remove all the soluble nitrogen constituents of the apple powder and the residual nitrogen may be regarded as "protein nitrogen". After the extraction the sample was dried at about 40°C and transferred from the packet to a 250 ml. round bottom flask. From this point the procedure was identical with that described for the estimation of total nitrogen.

Soluble nitrogen.

A value for the soluble nitrogen content was obtained by subtracting the value for the content of protein nitrogen from that for total nitrogen.

Soluble solids.

For the estimation of soluble solids a 2 gram sample of apple powder was weighed out in an aluminium

moisture can and 20 ml. of cold water was then added by means of a pipette. The mixture was allowed to stand with occasional stirring for about 15 minutes, which was found to be sufficient time for all the water-soluble materials in the powder to be leached out. The refractive index of the resulting liquor was then determined using an Abbé refractometer. From this reading the soluble solids content of the fruit was calculated on the assumption that sucrose constituted the major fraction of the total soluble solids.

Free acids.

After the refractive index had been determined for the estimation of soluble solids, the contents of the can were transferred to a 600 ml. conical beaker and diluted with about 150 ml. of water before being titrated with N/10 sodium hydroxide in the presence of phenolphthalein. The free acids content of the fruit was calculated from the titre obtained.

(6) EVALUATION OF STORAGE BEHAVIOUR

At intervals during the storage period the fruit was cursorily inspected for any evidence of the development of disorders. When it was apparent that a substantial proportion of the fruit had developed storage disorders of one kind or another, the samples were removed from the cool store and immediately weighed, graded for size, and counted. The colour and general appearance of the fruit was noted, and a preliminary examination for disorders was carried out. The fruit was then kept at room temperature

for two weeks before the final examination was made. In 1954 and 1956, ten fruits were taken from each storage sample for the estimation of firmness. In 1954, when the fruit as a whole was rather small, $2\frac{1}{4}$" fruits were used for these tests, while in 1956, because the fruit was generally larger, the tests were made on $2\frac{1}{2}$" fruits. From two opposite positions at the equator of these fruits, a portion of skin about 2 cm. in diameter was sliced off, and the resistance of the flesh to pressure was then determined by means of a penetrometer of the type originally devised by Magness and Taylor (1925) with modifications as described by Haller (1941).

The dates on which the fruit was removed from storage in the different years are set out below.

From the different orchards:	1954	6 November
	1955	25 October
	1956	17 September
From Plot X:	1954	10 November
	1955	18 October

RESULTS

The data obtained from the between-site investigations in the years 1954, 1955 and 1956 are presented in Tables I, III and V respectively of the Appendix. Comparable data for fruit from the 39 trees in Plot X appear in Tables II, IV and VI. Statistical data are recorded in Table VII.

I. CELL PHYSIOLOGY

The relation between fruit size and cell size.

Values observed in the course of these investigations for the mean fruit size per tree vary between about 60 and 140 grams, and this may be regarded as approximately the range of values generally met with in fruit of the Jonathan variety growing in Tasmania.

The strong positive correlation ($P < 0.01$) between mean fruit weight per tree and the mean cell volume of the fruits of the 85 - 95 gram group from each tree in the different orchards is illustrated in Figure 1 (a). The regression is linear over the range of fruit size met with, and the relation is seen to hold regardless of the site on which the fruit is grown. It does not differ significantly between the three seasons. Figure 1 (b) demonstrates the relationship ($P < 0.01$) observed in the 1954 and 1955 seasons in the fruit from the trees in Plot X. Cell size data for the 1956 fruit from this plot are not available at this stage.

It is clear from the figure that the relationship is the same between trees growing on different sites as between trees growing on one site. It is noteworthy that a comparison of the residual mean squares in the regressions by

the variance ratio test shows that the variation about the regression line is greater in 1954 ($P < 0.02$) amongst the trees in Plot X than amongst the trees in the different orchards. In 1955, however, there is no significant difference in this variation about the line.

In view of these findings, it is suggested that it is probably a general rule that within a given apple variety the greater the mean size of the fruit from a tree, the larger will be the cells in the fruit of any given size group from that tree. If, as suggested by Martin and Lewis (1952), cell size is important in determining the capacity of the fruit to store well, then the present findings underline the need for taking mean fruit size per tree into account when comparing the storage behaviour of fruit from different trees. The precaution taken by some workers of using in their comparisons only fruit of a certain size group would appear from these considerations to be of little, if any, value.

The relation between protein nitrogen and soluble nitrogen.

The positive relationship ($P < 0.01$) between the contents of protein and soluble nitrogen in the fruit from the trees in the different orchards is illustrated in Figure 2 (a). The relationship is independent of the site on which the fruit is grown, of the season, and of the total amount of nitrogen present in the fruit. In Figure 2 (b) the corresponding values have been plotted for the fruit from Plot X. Again it is apparent that the relationship is the same

between trees on different sites as between trees on one site. Only in 1956 did the fruit from the different orchards show a greater variation about the regression line than that shown by the fruit from Plot X.

Although the relationship does not depart significantly from linearity over the range of nitrogen contents observed, there is an apparent, and not unexpected, tendency for the soluble nitrogen content to increase much more rapidly with increasing protein nitrogen content when the total nitrogen content is really high. Over most of the range the soluble nitrogen content is increasing about twice as rapidly as the protein nitrogen content. This confirms for between-site variation a relationship already found within sites in other experiments in this laboratory (Martin, Lewis and Cerny, manuscript in preparation). Hulme (1956) has recently reported similar findings in Cox fruit from trees in one plot but receiving different fertilizer treatments, and also from trees growing in orchards widely separated geographically. While the regression lines obtained for Cox in England and Jonathan in Tasmania do not differ significantly in slope, the amount of soluble nitrogen associated with a given amount of protein nitrogen is considerably greater in the Tasmanian-grown Jonathan fruit.

Cell size in relation to respiration rate and protein nitrogen content.

(1) 1954 (a) Between trees in different orchards

Figure 3(a) shows that in the fruit from locality A greater cell size is associated with a proportionately greater

amount of protein nitrogen per cell. The correlation is significant at the 1% level, but for some reason does not hold for the fruit from the higher altitudes in this season.

If the concentration of protein nitrogen in the cytoplasm of an apple cell, and also the density of the cytoplasm, remain constant irrespective of the size of the cell, the amount of protein nitrogen per unit of cell surface area may be regarded, for purposes of comparison, as a measure of the thickness of the cytoplasmic lining. If these assumptions are true, then the observations just reported for the fruit from locality A may be taken to mean that in this fruit the protoplasm is of constant thickness whatever the mean cell size. This is in accord with recent observations in Tasmania in fruits of different varieties at two cropping levels (Martin and Lewis 1952).

No reliable data were obtained for the respiratory activity of the 1954 fruit.

(b) Between trees in one orchard

Figure 3(b) demonstrates the relationship ($P < 0.01$) between mean cell size and the amount of protein nitrogen in the cells in fruits from the different trees in Plot X. Protein nitrogen per cell increases somewhat more rapidly than cell size so that the amount of protein nitrogen per unit of cell surface area is increasing slightly with increase in cell size, as shown in Figure 3(c). Very similar findings have previously been reported for fruit from a similar group of Jonathan trees in one orchard (Martin et al. 1954).

(2) 1955

(a) Between trees in different orchards

Unfortunately, the number of trees used in the 1955 studies proved to be inadequate for the demonstration of any significant relationship between respiration rate, protein nitrogen content and cell size.

(b) Between trees in one orchard

In the fruit from the 39 trees in Plot X, an increase in the mean cell size is associated with a slower increase in the amount of protein nitrogen per cell, as illustrated in Figure 4(a). The correlation is significant at the 2% level. As a result, the amount of protein nitrogen per unit of cell surface area is decreasing with increasing cell size, as shown in Figure 4(b), the correlation being significant at the 5% level. This may mean that the cytoplasmic lining is thinner in the larger cells, which is in contrast to the observations regarding the fruit from this plot in the previous season.

Respiration per cell is positively correlated with cell size ($P < 0.01$), increase in cell size being accompanied by a slightly more rapid increase in respiration per cell. The result is a positive correlation ($P < 0.01$) between cell size and respiration per unit of cell surface area. These observations are illustrated in Figures 4(c) and 4(d). Hence because of the fall in the protein nitrogen per unit of cell surface area, there is a considerable increase in the respiration per unit of protein nitrogen (R/P) with increasing cell size. The correlation ($P < 0.01$) is shown in Figure 4(e).

This positive relationship between the ratio R/P and cell size is similar to that observed between varieties by Martin and Lewis (1952).

(3) 1956

(a) Between trees in different orchards

In the 1956 season, the fruit from localities A and C showed the expected correlation ($P<0.01$) between protein nitrogen per cell and cell size, the slope of the relationship not differing significantly between the two areas. From an inspection of Figure 5(a) it will be seen that an increase in cell size is accompanied by an equivalent increase in the amount of protein nitrogen per cell. Hence the amount of protein nitrogen per unit of cell surface area remains roughly constant irrespective of cell size (Figure 5(b)). In marked contrast, the fruit from locality B shows a distinct trend in the reverse direction. With increasing cell size, the amount of protein nitrogen per cell decreases rapidly. Thus the amount of protein nitrogen per unit of cell surface area shows a strongly negative correlation ($P<0.01$) with cell size.

Increase in cell size is associated with a considerably faster increase in the respiration per cell ($P<0.01$) as shown in Figure 6(a). Therefore with increasing cell size there is an increase in the respiration per unit of cell surface area ($P<0.01$) and in the R/P ratio ($P<0.01$). These increases are illustrated in Figures 6(b) and 6(c).

(b) Between trees in one orchard

Comparable data for the 1956 fruit from Plot X are not available at this stage.

The relation between free acids and total nitrogen

Free acids were determined in the 1955 and 1956 fruit only. In both years, the high altitude fruit had a higher mean content of free acids ($P < 0.001$) than that found in the low altitude fruit, suggesting that the latter fruit was more mature at harvest.

In the 1955 fruit from Plot X, a negative correlation ($P < 0.01$) was observed between the contents of free acids and total nitrogen. This is illustrated in Figure 7(a). The relationship was quite unexpected, and at this stage no explanation can be offered for it. In the same year the fruit from areas A, B and C showed no evidence for the existence of such a relationship (Figure 7(b)). In 1956, however, the picture was a completely different one. While the fruit from Plot X showed no relationship between the two variables (Figure 7(c)), that from the two high altitude localities B and C showed, not a negative, but a positive correlation ($P < 0.01$). Although this relationship, which is illustrated in Figure 7(d), does not appear to differ between these two localities, it does not extend to the fruit from locality A. The only explanation that may be offered at this stage for the positive relationship in the high altitude fruit is that higher nitrogen contents may have resulted in a proportionate general retardation in the maturation of the fruit, and that one of the ways in which this retardation has manifested itself has been a proportionate slowing down of the rate of acid loss. However, this suggested explanation does not account for the absence of any correlation in the fruit

from locality A and from Plot X.

The relation between soluble solids content and fruit and cell size

Soluble solids were determined only in the fruit of the 1956 season, and are shown in Figure 8(a) to be positively correlated with mean cell size ($P < 0.01$) in the fruit from the three different localities. As cell size data for the fruit from Plot X are not yet available for purposes of comparison, soluble solids have been plotted in Figures 8(b) and 8(c) against mean fruit weight per tree for the fruit from areas A, B and C, and from Plot X respectively. Because soluble solids were determined only in the fruit of the 85 - 95 gram group, the relationship might be expected to become insignificant when mean fruit weight per tree is substituted for the mean cell size of the fruit of this size group. However, while the between-site relationship retains its significance at the 1% level, there is no suggestion whatever of any within-orchard relationship. It is not possible at this stage to suggest an explanation for the existence of a relationship which obtains in fruit from different sites in three different localities, and yet does not appear to hold for a number of trees of the same age growing in one orchard under conditions which are uniform for each tree in almost every respect.

II. RESULTS OF STORAGE TESTS

At the time of writing this thesis the current year's fruit from Plot X has not been removed from storage for the evaluation of storage behaviour as it constitutes a

portion of the material being used in some concurrent investigations. This applies also to the fruit from the four trees of site A5. No storage data are available for the current season's fruit from area B because, owing to hail injury, the storage samples from this area had to be discarded early in the storage period.

Firmness in relation to mean fruit weight

Estimation of the firmness or resistance to pressure of the stored fruit was made only in the years 1954 and 1956. In the first year fruit of the $2\frac{1}{4}$" size group was used for these tests, while in 1956 $2\frac{1}{2}$" fruit was substituted because of the generally greater fruit size in this year. In Figure 9(a) the 1954 values for the mean penetrometer readings for ten apples have been plotted against the mean fruit weight per tree. The values for the fruit from trees 1 and 2 in all the high altitude orchards have been omitted from the graph as there was no evidence of a correlation between the variables in this fruit. This is probably due to the fact that the fruit was picked in an immature condition. However, the fruit picked about two weeks later from trees 3 and 4 in these orchards shows a positive linear relationship ($P<0.05$) between firmness and mean fruit weight per tree, as does also the fruit from the orchards in locality A ($P<0.01$). While the regression lines for the fruit from locality A and for that from the high altitude localities do not differ significantly in slope, they are a significant distance apart. For a given mean fruit weight per tree the high altitude fruit

is firmer, which suggests that this fruit was probably less mature at harvest than that from locality A.

Figure 9(b) shows that in the same year the fruit from Plot X failed to show any relationship between firmness and mean fruit weight per tree similar to that observed in the between-site studies. This absence of any relationship within an orchard is rather surprising, and furnishes a further case of a relationship which obtained between trees in different orchards and yet not between trees in one orchard.

The fruit from areas A and C in 1956 show a relationship very similar to that observed in 1954. The correlation is significant at the 1% level for the fruit from area A, but is not significant for that from area C, doubtless due to the inadequate number of observations. Nevertheless, Figure 9(c) suggests that had there been a sufficient number of samples the regression lines would probably have been parallel. As in 1954, there is a suggestion that for a given mean fruit size per tree the high altitude fruit is firmer, indicating that this fruit was probably less mature at harvest than the low altitude fruit picked at the same date.

In the fruit from three out of the four trees in orchard A3, the increase in mean fruit size occurring during the period between the first and second pickings is associated with a slight falling off in firmness after storage compared with the fruit from the earlier pick. This may be explained on the basis of a substantial difference in maturity between fruit of the two picks at the time it was placed in cool storage.

The incidence of breakdown in relation to mean fruit weight

1954

In the fruit from Plot X in the 1954 season the occurrence of breakdown was so slight that no data for this disorder have been included in the table.

Figures 10(a), 10(b) and 10(c) illustrate the relationships observed in the 1954 fruit, from localities A, B and C respectively, between the incidence of breakdown and the mean fruit weight per tree. Some interesting between-area differences are apparent, while there is no evidence of any between-site differences in the relationship within any one area. In the fruit from area A, appreciable percentages of breakdown occurred only when the mean fruit weight per tree exceeded 100 grams. In the fruit from the two high altitude areas, on the other hand, breakdown occurred in considerable amounts with values for the mean fruit weight as low as 70 to 80 grams. In each of the high altitude areas the relationship is a linear one, the correlations being significant at the 5% level for area B and at the 1% level for area C. There is no evidence that the fortnight's delay in picking the fruit from trees 3 and 4 in these orchards has influenced the relationship in any way, although this cannot be proved conclusively without a greater number of observations. It would appear that the increased incidence of breakdown in the fruit from trees 3 and 4 is due solely to the greater mean fruit size acquired during the longer period on the tree. There is a significant difference ($P < 0.01$) in the slope of

the regression lines for the two areas. Fruit from area C shows a larger increase in breakdown incidence with a given increase in mean fruit weight than that observed in the fruit from area B. It is concluded that in the 1954 season the fruit from area A was of superior keeping quality, from the point of view of breakdown, to that of area B, and that this in turn was superior to the fruit of area C.

1955

In this year greater percentages of breakdown occurred in the fruit from Plot X than had been observed in the previous season's fruit, and incidence was positively correlated ($P < 0.05$) with mean fruit size per tree, as shown in Figure 10(d). Where the mean fruit weight was less than 80 grams, little or no breakdown occurred, while with increasing mean fruit weight above this figure there was a steep rise in the breakdown incidence which did not depart significantly from linearity over the range of fruit size encountered.

The corresponding data for the fruit from areas A, B and C are presented in Figure 10(e). The correlation is significant at the 5% level. The form of the relationship is very similar to that observed in the fruit from Plot X, both in slope and position, and the amount of variation about the regression line is not significantly greater than that occurring in the Plot X fruit. It is noticeable that there is no difference in this relationship between the different areas as was the case in the previous season. The smaller

number of trees used in the between-site investigations in this season renders it impossible to draw any very definite conclusions from these results, but it would appear that some climatic or soil factor or combination of factors which was operating in or prior to the 1954 growing season to induce between-locality differences in the 1954 fruit in the relationship under discussion was not in operation in the corresponding period in the following year.

Tree 2 in orchard A3 has been omitted from Figure 10(e) because of its extraordinarily low breakdown percentage relative to mean fruit size. Although the disorder deep scald did not develop in any of the other fruit used in the investigations in 1955, 50% of the fruit from this tree was affected with this disorder, suggesting that the two disorders, breakdown and deep scald, may be mutually exclusive. There were no obvious differences between trees 1 and 2 or in the cell physiology of their fruit which would provide any clue as to the reason for the marked differences in storage behaviour observed.

1956

Data for breakdown incidence in the 1956 fruit from Plot X are not yet available.

Breakdown incidence in the fruit from localities A and C has been plotted in Figure 10(f). Where values for the mean fruit size are less than 125 grams, no appreciable amount of breakdown has occurred. This leaves only four samples in which significant percentages of breakdown have been observed,

and two of these are of fruit picked from trees in orchard A3 about a month after the first picking date. There is not sufficient evidence to prove whether the month's delay in picking has or has not influenced the susceptibility of the fruit to breakdown other than by allowing the fruit to acquire a considerably greater mean size.

The incidence of rots in relation to mean fruit weight

1954

The incidence of rots in the fruit from the different trees of Plot X in the 1954 season is positively correlated ($P < 0.05$) with mean fruit size per tree. This relationship is illustrated in Figure 11(a).

In the fruit from each of the areas A, B and C, a positive correlation exists between the variables, the correlations being significant at the 1%, 5% and 1% levels respectively. Variation about the regression line is significantly greater ($P < 0.02$) in the fruit from area A than is shown by the fruit from Plot X. Figures 11(b), 11(c) and 11(d) show that there are between-area differences in the relationship, similar to those observed for breakdown in the same season. In the case of rots, however, there are significant differences ($P < 0.01$) in regression slopes between areas A and B, and between B and C, but not between A and C. The fruit from area B shows a lower incidence of rots relative to mean fruit size than that observed in the fruit from the other areas. It may thus be regarded as of slightly superior keeping quality, from the point of view of

resistance to fungal infection, when compared with the fruit from localities A and C. There is no evidence to suggest that there is any increase in susceptibility to rotting in the fruit from trees 3 and 4 in the high altitude orchards which cannot be accounted for on the basis of the greater mean fruit size per tree.

1955

The correlation between rot incidence and mean fruit weight in the fruit from Plot X in the 1955 season is more significant ($P < 0.01$) than in the previous season, and is illustrated in Figure 11(e).

In the fruit from areas A, B and C, the occurrence of rots was again correlated ($P < 0.05$) with mean fruit size, as shown in Figure 11(f), but in this season there was no apparent difference in the relationship between areas. The smaller number of samples used in this season's investigations renders it impossible to make any definite inference on this point. However, if there are in fact no between-area differences in the relationship, it would seem that some environmental difference obtaining between the areas at some stage during the development of the 1954 fruit did not exist at the corresponding stage in the development of the following season's fruit.

The variation about the regression line for the fruit from area A is not significantly greater than that observed in the fruit from Plot X.

1956

Data for the incidence of rots in the 1956 season

are available only for the fruit from areas A and C. Figure 11(g) illustrates the correlation ($P < 0.01$) between the incidence of rots and mean fruit weight per tree. There was an apparent tendency for the fruit from area C to develop a higher percentage of rots relative to mean fruit size than was the case in the fruit from area A, but there is not a sufficient number of points to render this suspected difference significant. As was the case with breakdown, rot susceptibility in the fruit of the second pick from the trees in orchard A3 appears to conform to the relationship existing in the fruit picked at the normal time. Once again, the increase in the incidence of disorder in this fruit may be accounted for by the increase in mean fruit size.

The incidence of deep scald in relation to mean fruit weight

No deep scald was observed in any of the fruit of the 1954 and 1955 seasons, except in that from tree 2 in orchard A3 in 1955. In 1956, again with the exception of the fruit from this tree, deep scald occurred in appreciable amounts only where the mean fruit weight exceeded 120 grams. The data have been plotted in Figure 12(a). Although only 7 samples had mean fruit weights of 120 grams or more, they represent 4 different orchards and both picks from orchard A3. The correlation ($P < 0.01$) is linear over the small range of fruit size, and in the fruit from the second pick in orchard A3 there is no apparent increase or decrease in deep scald incidence due to the more advanced maturity at harvest. The fruit of the second pick from tree 2 in this orchard showed an exceptionally high percentage of this disorder and a

complete absence of breakdown. As in the previous season there was nothing exceptional about the mean cell size, chemical composition or respiration rate of this fruit which might afford any clue as to its abnormal behaviour in storage in comparison with tree 1 which is adjacent to this tree in the orchard, of the same age, size, and vigour, and yielding crops of approximately the same size. Apparently some tree factor other than mean fruit size has operated in both 1955 and 1956 to induce a marked susceptibility to the disorder. Data for the 1954 fruit from this tree is unfortunately not available. At the beginning of 1955 the tree was substituted for the one designated tree 2 in the first year of the investigations.

The incidence of Jonathan Spot in relation to mean fruit weight

The 1956 season was the only one in which Jonathan Spot occurred in the fruit under investigation. Figure 12(b) illustrates the positive correlation ($P < 0.01$) between the incidence of this disorder and mean fruit weight per tree. There is no evidence pointing to any difference in the relationship between the two areas A and C, but there is a suggestion that there has been a slight increase in susceptibility relative to mean fruit weight in the fruit from the second pick in orchard A3. However, the levelling out of the relationship at the 100% disorder level, and the fact that all the fruit of two of the late picked samples had apparently developed the disorder well before the fruit was examined, disallow any conjecturing on this point.

CONCLUSIONS

A highly significant linear relationship has been reported (Martin et al. 1954) between the mean weight and mean cell size of the fruit from different trees in the same orchard. A relationship has now been found to exist, amongst trees within one orchard, and amongst trees in different orchards in three localities, between the mean fruit weight per tree and the mean cell size of the fruit of the 85 - 95 gram group from each tree. Over three seasons, between-site and between-season differences in environment have not resulted in any significant differences in the relationship between these variables. Variation about the regression line for fruit from different sites has been found to be no greater than that observed to occur within one orchard. This implies that differences between trees due to the influence of locality factors and orchard factors, including cultural treatments, of the order occurring in this experimental material are of little importance compared with the differences between trees in one orchard, even when such an orchard has been chosen especially for its uniformity, as was the case with Plot X.

The relationship between mean fruit weight per tree and mean cell size of the 85 - 95 gram fruit probably differs between varieties, since it has been demonstrated (Smith 1950, Martin and Lewis 1952) that characteristic varietal fruit size is determined primarily by the number of cells going to make up the fruit, and that variation in cell size is of secondary importance in this connection.

Another relationship which is apparently unaffected by between-site and between-season differences in the environment is that which has been observed between the contents of protein nitrogen and soluble nitrogen in the fruit. Again, between-site variation about the regression line is no greater than that which was observed within one orchard. The relationship reported here for fruit from different sites is identical with that which has been observed in this laboratory over several years in the fruit from a large number of Jonathan trees growing in one orchard but receiving different nitrogen treatments. The fact that the relationship reported by Hulme (1956) for fruit of the Cox variety grown in England is somewhat different from that observed with Jonathan fruit in Tasmania suggests that this relationship also varies between different apple varieties.

The relationships between the size of the cell and its respiratory activity and protein nitrogen content are not consistent from year to year, either within one orchard or between different orchards. Experimental error may be responsible for the fact that respiration rate has not in all cases shown significant relationships with the other variables. The cytoplasmic layer has been shown to be sometimes thicker and sometimes thinner (or more concentrated or dilute in protein content) in larger cells than in smaller ones.

Although Hulme (1951) considered that the respiration per unit protein (R/P) might have a roughly

constant value within a variety, independent of the locality in which the fruit is grown, the present findings indicate that the R/P ratio is not constant, but increases with increase in cell size, at least in the Jonathan variety. A similar positive relationship between cell volume and the R/P ratio has been reported for fruit of a number of different varieties grown in Tasmania (Martin and Lewis 1952). Apparently with larger cells a greater amount of energy from respiration is required for the maintenance of a given amount of protein. The increase in the ratio with increase in cell size may indicate a general decline in the efficiency of the energy-transfer mechanisms in the larger cells. Although none of the disorders is correlated significantly with the R/P ratio (which may be to some extent due to differences in precision in the different determinations), there may be a link here with the close relationships observed between fruit size and cell size, and between fruit size and disorder incidence.

The inconsistency found between areas and between seasons in the relationship between the contents of total nitrogen and free acids in the fruit cannot be explained at this stage, nor can the fact that the between-site relationship observed between the soluble solids content and the mean fruit weight per tree did not hold between trees growing on one site under very uniform conditions.

The higher free acids content observed in the fruit from the high altitude orchards in the two years when estimations were made suggests that this fruit is slower in

reaching maturity than that grown at lower altitudes. This is the general opinion amongst growers, and is borne out by the observation that the high altitude fruit was firmer, relative to mean size, after the storage period, than that from area A, even when the former fruit was picked considerably later, as was the case in 1954. Two other phenomena associated with immaturity, viz. a delay in the change of the colour of the skin from green to yellow, and a greater tendency to shrivel during cool storage, have been observed, in varying degree, in the fruit from areas B and C in all three seasons. The slower rate of maturation of the fruit from these areas could be explained on the basis of a lower mean temperature during the growing season. Unfortunately, no meteorological data for the three growing seasons are available for any of the localities, although temperature records begun in March 1956 show that the high altitude areas are slightly colder than area A, at least during autumn, winter and spring. The general view amongst growers is that although flowering occurs at about the same time in the high altitude areas, it is soon noticeable that fruit development is lagging behind that in the low altitude areas.

The tradition that high altitude fruit has superior keeping quality must rest solely upon its greater firmness due to its less mature condition at the normal picking date. Its susceptibility to storage disorders in relation to mean size was found to be as high as, and at times higher than, that found in the low altitude fruit.

Besides differences in mean temperature, and perhaps rainfall, in the high altitude and low altitude orchards, there is considerable variation in the type of soil in the different orchards, and also in the manurial treatment given by the growers, as indicated in the brief outline in the Appendix of the fertilizer programmes which the growers have conducted since 1953. Between-site differences in these environmental factors might well be expected to result in marked between-site differences in the keeping quality of the fruit. From the observations of three consecutive seasons regarding the susceptibility of the fruit to storage disorders, it would appear that if any of these factors has in fact exerted a differential effect on keeping quality, it has done so only indirectly through an effect upon the mean fruit size per tree. This is true at least in 1955 and 1956. In 1954, the differences in disorder incidence relative to mean fruit weight occurring in the different areas were apparently due to some between-area climatic difference occurring in that season and exerting its effect through some other means than through an influence on mean fruit size. Because there is considerable between-site variation in soil type or manurial treatment or both within each area, and because the between-area differences in the disorder incidence - mean fruit size relationship did not occur in the two following seasons, it seems safe to assume that the differences in the relationship in 1954 were not the result of differences in soil type or manurial treatment.

Because identical storage conditions could not be reproduced from season to season, it is not possible to draw any definite conclusions from the seasonal variation in disorder level. Nothing has emerged from these investigations which would either confirm or conflict with the finding of Martin (1954b) that such variation between seasons, in fruit of the Cox, Jonathan and Cleopatra varieties, was mainly related to differences in mean fruit size, although direct climatic effects of lesser importance did exist.

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NOTE

It is hoped to publish the results described in this thesis as a short paper in the series of papers which have appeared in the Australian Journal of Biological Sciences under the series title: "Physiology of growth in apple fruits".

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APPENDIX

NOTES ON MANURIAL PROGRAMMES

It is difficult in some cases to obtain very precise information regarding the nature of the fertilizers used in different orchards. Moreover, a grower who does not use a mobile spreader usually varies the amount of fertilizer applied to individual trees according to their size and apparent condition. The fertilizer most commonly used amongst growers is a mixture containing nitrogen, phosphorus and potassium in the proportions 2 NH_3 : 2 P_2O_5 : 1 K_2O. In several of the orchards from which fruit was taken for the between-site studies this mixture has been applied annually at rates varying from $3\frac{1}{2}$ to 11 lbs. per tree. In three other orchards it has been used in alternate years, with applications in the intervening years of potassium chloride at the rate of about $1\frac{1}{2}$ lbs. per tree. Although in one orchard potassium chloride applied at this rate has for several years been the only fertilizer used, the fruit does not show any signs of nitrogen deficiency.

Orchard A 1 N P K each year.
A 2 K with much smaller amounts of N and P each year.
A 3 N P K each year.
A 4 N P K each year.
A 5 N in 1955 only.
A 6 N P K each year.
B 1 N P K and K in alternate years.
B 2 N P K and K in alternate years.
B 3 N P K each year.
C 1 K each year.
C 2 N P K each year.

TABLE I. AREAS A, B AND C. 1954

Orchard	Tree No.	Mean fruit wt. (g)	% Dry Matter	Cell Volume c.c.x 10^{-8}	Total N % dry wt. x 10^{-3}	Protein N % dry wt. x 10^{-3}	Protein N/cell g. x 10^{-11}	Soluble N % dry wt. x 10^{-3}	% Breakdown	% Rots	Penetrometer reading lbs.
A1	1	95	14.5	169	203	118	32	85	3	49	10.2
	2	87	14.7	174	188	119	34	69	8	27	10.3
A2	1	89	14.7	209	163	112	38	51	2	37	10.0
	2	84	14.7	195	140	103	36	37	1	36	10.5
A3	1	82	14.9	207	159	111	38	48	2	31	10.6
	2	102	15.2	211	174	104	40	70	7	54	11.1
A4	1	76	16.5	180	153	112	37	41	2	15	10.4
	2	90	14.5	183	184	127	37	57	0	16	10.4
A5	1	85	14.4	175	179	114	32	65	0	9	9.8
	2	82	15.0	159	217	124	33	93	1	20	9.8
A6	1	111	16.2	214	173	108	43	65	47	55	11.4
	2	113	16.7	212	173	111	46	62	40	71	11.2
B1	1	80	14.2	175	193	121	33	72	1	11	12.3
	2	78	14.1	161	195	130	32	65	2	14	11.8
	3	81	14.0	183	212	141	40	71	16	27	10.9
	4	83	14.6	189	163	109	33	54	8	19	11.2
B2	1	74	14.6	187	175	123	37	52	10	11	13.4
	2	73	15.0	181	179	114	34	65	18	13	11.4
	3	78	14.3	169	265	148	39	117	20	24	11.9
	4	82	15.0	179	272	149	44	123	34	25	11.4
B3	1	65	15.1	136	297	161	36	136	0	8	12.4
	2	66	14.5	152	252	152	37	100	1	14	11.5
	3	96	15.3	190	173	118	38	55	25	21	12.4
	4	88	15.1	188	167	106	33	61	32	29	11.5
C1	1	75	14.7	189	150	105	32	45	9	14	11.9
	2	73	14.7	180	191	123	36	68	20	30	12.5
	3	83	14.6	198	169	118	38	51	68	47	11.2
	4	79	14.5	191	178	128	39	50	33	45	11.2
C2	1	71	13.4	158	265	168	39	97	9	20	11.7
	2	72	13.0	172	255	155	38	100	17	25	12.0
	3	82	14.2	179	262	153	43	109	75	47	11.4
	4	76	14.2	186	229	156	45	73	50	33	11.0

TABLE II. PLOT X. 1954.

Tree No.	Mean fruit wt. (g.)	% Dry matter	Cell Volume c.c. $x10^{-8}$	Cell Surface $cm.^2 x10^{-5}$	Total N % dry wt. $x10^{-3}$	Protein N % dry wt. $x10^{-3}$	Protein N /cell g. $x10^{-11}$	Protein N $g.x10^{-7}$ $km.^2$ cell surface	Soluble N % dry wt. $x10^{-3}$	Penetrometer reading lbs. $x10^{-1}$	% Rots
1	83	14.7	190	75	187	129	40	53	58	100	14
2	86	14.4	187	74	216	135	40	54	81	99	13
3	78	15.1	175	71	206	142	41	58	64	105	5
4	95	15.2	205	79	145	106	37	46	39	106	8
5	86	14.4	200	78	203	137	43	56	66	-	6
6	82	15.2	201	78	171	122	41	53	49	108	7
7	94	14.9	198	77	190	126	41	53	64	98	20
8	82	15.2	185	74	157	117	36	49	40	97	11
9	73	14.9	161	68	142	109	29	42	33	99	3
10	72	14.8	178	72	191	131	38	53	60	94	5
11	78	15.2	182	73	178	127	39	53	51	100	11
12	78	15.3	180	73	140	104	32	43	36	104	13
13	73	15.0	187	74	165	124	39	52	41	112	10
14	76	14.6	200	78	157	115	37	47	42	106	8
15	84	15.6	191	78	150	119	36	47	39	106	6
16	79	15.2	202	78	174	130	44	56	44	97	11
17	74	14.9	161	68	160	112	31	45	48	109	4
18	73	14.9	165	69	164	117	32	46	47	103	3
19	77	15.2	165	69	175	117	32	47	58	110	5
20	76	15.0	177	72	173	121	35	49	52	106	3
21	89	15.3	205	79	141	108	38	47	33	100	6
22	81	14.7	210	80	154	114	39	49	40	100	6
23	79	15.2	216	81	160	116	42	52	44	110	3
24	99	15.9	256	91	137	105	47	52	32	106	7
25	68	14.1	165	69	266	156	40	58	110	97	7
26	82	15.1	193	76	161	121	39	51	40	100	5
27	73	14.2	163	69	180	127	32	47	53	92	2
28	77	14.5	182	73	198	127	37	50	68	100	9
29	76	14.5	219	82	177	127	44	54	52	105	6
30	85	14.8	220	82	183	130	42	52	53	103	5
31	89	14.6	225	84	168	120	43	52	48	98	9
32	87	15.4	226	84	168	122	47	56	46	101	6
33	83	14.6	188	75	176	115	35	46	61	87	30
34	73	15.1	160	68	142	101	32	47	41	100	3
35	84	15.3	182	73	147	108	33	45	39	95	6
36	83	15.1	188	75	165	117	35	47	48	94	0
37	78	15.0	183	74	137	103	32	43	34	100	2
38	77	14.2	165	69	151	113	29	42	38	100	2
39	78	14.6	172	70	170	124	34	49	46	101	9

TABLE III. AREAS A, B AND C. 1955.

Orchard	Tree No.	Mean Fruit wt.(g.)	% Dry matter	Cell volume c.c.x10^{-8}	Respiration rate mg.CO_2/ 10Kg./hr.	Respiration mg.CO_2/hr. x10-10	Total N % dry wt. x10^{-3}	Protein N % dry wt. x10^{-3}	Protein N/cell g.x10^{-11}	Soluble N % dry wt. x10^{-3}	Free acids % dry wt. x10^{-2}	% Breakdown	% Rots
A1	1	94	16.3	209	102	23	164	116	44	48	288	12	17
	2	-	17.5	202	126	28	157	115	45	42	216	-	-
A2	1	106	14.0	218	95	23	144	109	37	35	324	15	14
	2	115	13.1	234	85	22	108	86	29	22	309	36	19
A3	1	111	15.5	263	115	-	131	97	43	34	357	43	26
	2	107	15.1	259	109	-	135	102	44	33	320	5	13
A4	1	106	16.8	234	111	29	166	121	52	45	316	59	21
	2	110	16.0	232	96	25	173	123	50	50	243	58	27
A5	1	101	19.2	208	150	-	139	102	45	37	370	41	32
	2	80	18.7	193	156	-	225	141	56	84	305	6	9
B1	1	105	17.3	239	114	30	103	80	36	23	396	32	19
	2	109	18.0	258	107	30	112	91	46	21	408	47	16
B2	1	89	17.7	226	131	33	182	124	55	58	436	42	21
	2	99	17.7	241	-	-	149	107	50	42	397	78	31
B3	1	90	16.4	207	122	28	116	89	33	27	334	5	3
	2	86	17.3	219	119	29	170	91	38	26	371	7	2
C1	1	98	16.6	248	101	28	127	93	42	34	416	50	17
	2	93	15.4	236	100	26	118	90	36	28	430	41	20
C2	1	96	15.2	211	110	26	148	111	39	37	293	36	21
	2	99	17.3	226	114	28	162	112	48	50	427	31	13

TABLE IV. PLOT X. 1955

Tree No.	Mean Fruit wt.(g)	% Dry matter	Cell Volume c.c.x10^{-8}	Cell Surface area cm.^{2}x10^{-5}	Resp.rate mg.CO_2/ 10Kg./hr.	Resp./cell mg.CO_2/hr. x10^{-10}	Resp./cm.^{2} cell surface area mg.CO_2/hr. x10^{-7}	Resp.mg. CO_2/g. Protein N/hr. x10^{-2}	Total N % dry wt. x10^{-3}	Protein N % dry wt. x10^{-3}	Protein N/cell g.x10^{-11}	Protein N g./cm.^{2} cell surface x10^{-7}	Soluble N % dry wt. x10^{-3}	Free acids % dry wt.-2 x10^{-2}	% Breakdown	% Rots
1	81	18.5	141	63	145	23	36	60	199	131	38	60	68	257	1	11
2	94	18.5	147	64	160	26	40	69	192	125	39	61	67	224	9	23
3	87	17.8	182	73	142	29	39	66	163	120	43	59	43	273	3	15
4	95	17.4	243	88	141	38	43	93	120	87	41	46	33	379	12	18
5	92	19.4	190	75	152	32	42	70	151	111	45	60	40	270	13	26
6	61	20.3	156	67	98	17	25	39	169	125	44	65	44	232	0	4
7	82	19.9	152	66	129	22	33	54	182	121	40	61	61	234	0	12
8	68	21.2	151	65	130	22	33	54	139	114	40	62	25	231	0	6
9	71	21.6	179	72	164	32	45	68	141	111	47	66	30	321	1	7
10	72	20.2	143	64	126	20	31	48	183	131	42	65	52	301	1	15
11	69	20.8	168	70	138	26	36	54	157	123	47	66	34	256	0	5
12	60	20.7	146	64	123	20	31	48	149	123	41	64	26	226	0	4
13	71	20.5	163	69	148	27	38	66	143	110	40	58	33	275	4	7
14	89	19.6	201	78	140	31	40	73	135	98	43	54	37	278	11	27
15	69	20.3	172	70	126	24	34	59	134	105	41	58	29	241	0	3
16	65	21.0	186	74	139	28	38	56	146	118	51	69	28	237	0	5
17	68	20.4	172	70	141	27	38	64	140	109	42	60	31	288	0	3
18	69	21.5	163	69	191	34	50	75	169	119	44	63	50	326	0	11
19	70	20.2	174	71	161	31	43	66	172	122	47	66	50	280	1	11
20	67	20.9	172	70	149	28	40	65	152	110	44	63	42	285	1	6
21	72	19.5	158	67	130	23	34	65	133	102	35	52	21	242	0	3
22	67	20.1	168	70	109	20	29	47	162	115	46	65	47	287	0	5
23	83	19.9	196	76	155	33	44	87	117	90	39	51	27	303	3	17
24	74	23.0	171	70	149	28	40	67	119	97	42	60	22	276	0	4
25	72	20.0	177	72	175	34	47	72	165	121	47	66	44	252	1	9
26	64	21.1	144	64	115	18	28	46	156	118	39	60	38	241	0	2
27	83	19.0	195	76	130	28	37	59	170	116	47	62	54	336	20	31
28	73	20.1	176	71	137	26	37	61	154	112	44	61	42	293	6	11
29	104	19.9	240	87	132	35	40	75	124	89	47	54	35	369	62	48
30	102	18.9	225	84	120	30	35	66	126	96	45	54	30	340	30	37
31	95	18.8	186	74	112	23	31	58	136	102	40	53	34	264	34	45
32	94	19.8	194	76	164	35	46	80	135	104	44	58	31	252	19	17
33	101	19.2	190	75	150	31	42	77	139	102	41	55	37	316	45	32
34	72	19.7	203	79	167	37	47	81	139	105	46	58	34	315	3	17
35	69	18.9	146	64	128	21	32	65	134	104	32	49	30	287	0	3
36	68	20.3	160	68	138	24	36	62	148	110	39	58	38	256	4	12
37	73	19.6	177	72	119	23	32	67	115	91	35	48	24	318	0	7
38	86	19.9	172	70	132	25	36	75	115	89	32	45	26	344	26	20
39	67	19.7	162	68	116	21	30	54	141	109	39	57	32	275	4	7

TABLE V. AREAS A, B, AND C. 1956

Orchard	Tree No.	Mean fruit wt. (g.)	% Dry matter	Cell volume c.c. $x10^{-8}$	Cell surface area $Cm.^2$ $x10^{-5}$	Respiration rate mg.CO_2/10Kg./hr.	Respiration/ cell mg.CO_2/ hr. $x10^{-10}$	Respiration/ $cm.^2$ cell surface area mg.CO_2/hr.$x10^{-7}$	Respiration mg.CO_2/g. Protein N/hr.$x10^{-2}$	Total nitrogen % dry wt. $x10^{-3}$	Protein nitrogen % dry wt. $x10^{-3}$	Protein nitrogen/ cell g. $x10^{-11}$	Protein N g.$x10^{-7}$/$cm.^2$ cell surface	Soluble N % dry wt. $x10^{-3}$	Free acids %dry wt. $x10^{-2}$	Soluble solids % fresh wt. $x10^{-1}$	% Breakdown	% Rots	% Deep Scald	% Jonathan Spot	Penetrometer reading lbs.
A1	1	122	14.0	228	85	248	62	73	126	210	140	49	58	70	322	109	2	16	0	35	10.7
	2	85	14.4	209	80	246	57	71	119	212	144	48	60	68	236	111	0	9	0	26	9.0
	3	103	13.9	217	82	188	45	55	94	213	143	48	58	70	285	113	0	5	0	6	8.8
	4	106	14.5	210	80	272	63	79	126	239	149	50	62	90	299	112	0	2	0	5	8.8
A2	1	106	13.1	267	94	252	74	79	187	130	103	40	42	27	168	103	3	14	0	73	10.4
	2	104	13.9	225	84	236	59	70	123	198	139	48	57	59	321	108	0	16	0	51	9.8
	3	114	15.4	258	92	270	77	83	166	136	106	46	50	30	348	120	4	36	0	27	9.6
	4	120	15.5	268	94	226	67	71	120	174	121	56	59	53	327	121	0	39	2	76	10.6
A3	1	99	15.8	248	89	248	68	76	133	168	118	40	45	50	299	123	0	3	0	48	9.9
Pick 1	2	100	14.9	288	99	252	80	81	165	138	103	48	49	35	167	117	0	5	2	60	11.7
	3	130	18.0	307	104	421	142	137	229	140	102	62	60	38	371	141	7	26	5	62	12.2
	4	123	14.6	291	100	319	102	102	133	248	140	65	65	108	226	115	1	16	3	58	11.4
A3	1	103	15.3	268	-	-	-	-	-	174	116	-	-	58	262	120	0	12	2	81	10.5
Pick 2	2	117	16.4	304	-	-	-	-	-	149	105	-	-	44	272	132	0	52	56	98	11.2
	3	135	16.0	345	-	-	-	-	-	150	96	-	-	54	341	124	52	66	17	100	11.7
	4	142	18.4	322	-	-	-	-	-	182	114	-	-	68	303	144	22	62	21	100	11.2
A4	1	105	12.2	222	83	282	69	83	125	322	185	55	66	137	231	105	0	11	0	15	8.5
	2	102	14.0	208	80	227	52	65	100	295	161	52	65	134	305	102	0	20	0	7	8.6
	3	112	13.7	225	84	-	-	-	-	270	161	55	65	109	361	103	2	28	0	28	9.5
	4	100	14.1	227	84	172	43	51	83	262	146	52	61	116	358	106	3	13	0	10	9.2
A5	1	109	15.8	234	86	-	-	-	-	207	138	56	65	69	270	124	-	-	-	-	-
	2	120	15.1	286	99	-	-	-	-	179	137	65	69	42	161	122	-	-	-	-	-
	3	99	15.3	273	96	-	-	-	-	170	127	59	61	43	144	123	-	-	-	-	-
	4	93	15.6	250	90	-	-	-	-	167	122	52	58	45	229	124	-	-	-	-	-
A6	1	112	15.3	263	93	215	62	67	109	188	129	57	61	59	300	118	0	10	1	49	10.3
	2	127	16.4	288	99	302	96	96	140	184	132	68	69	52	184	127	9	44	15	100	11.4
	3	110	14.9	316	106	292	101	96	155	169	126	65	62	43	177	118	0	6	0	52	11.0
	4	113	16.1	284	98	248	78	79	129	161	120	60	61	41	309	123	0	10	2	28	10.7
B1	1	99	13.1	257	91	255	72	79	199	120	98	36	40	22	204	102	-	-	-	-	-
	2	110	13.1	219	82	225	54	66	134	166	128	52	63	38	383	102	-	-	-	-	-
	3	110	12.2	243	88	187	50	57	134	141	115	37	43	26	200	98	-	-	-	-	-
	4	114	13.1	243	88	231	62	70	149	152	118	42	47	34	333	104	-	-	-	-	-
B3	1	107	14.5	252	90	224	62	69	129	155	120	48	54	35	233	108	-	-	-	-	-
	2	97	13.5	223	83	265	65	78	127	243	154	51	61	89	472	106	-	-	-	-	-
	3	102	12.8	233	86	290	74	86	158	237	144	47	55	93	453	103	-	-	-	-	-
	4	106	13.5	238	87	266	70	80	132	234	149	53	60	85	371	102	-	-	-	-	-
C1	1	96	13.7	201	78	258	57	73	127	226	148	45	58	78	453	103	0	16	0	6	10.1
	2	85	13.4	213	81	234	55	68	129	196	136	43	53	60	429	100	0	22	0	17	9.4
	3	90	13.0	210	80	273	63	79	134	232	157	47	59	75	427	102	0	9	0	4	9.2
	4	86	13.0	194	76	-	-	-	-	206	143	40	52	63	432	97	0	16	0	18	9.1
C2	1	82	14.6	203	78	202	45	58	87	295	158	52	66	137	487	115	0	7	0	1	9.1
	2	90	14.4	222	83	213	52	63	93	298	158	56	67	140	477	109	0	8	0	0	10.3
	3	81	14.5	208	80	254	58	73	125	236	141	47	58	95	385	111	0	5	0	0	9.7
	4	89	13.2	217	82	205	49	60	93	371	168	53	65	203	547	99	0	11	0	0	10.4

TABLE VI. PLOT X. 1956.

Tree No.	Mean Fruit wt.(g.)	% Dry Matter	Resp. Rate mg.CO_2/ 10 Kg./hr.	Total N % dry wt. $\times 10^{-3}$	Protein N % dry wt. $\times 10^{-3}$	Soluble N % dry wt. $\times 10^{-2}$	Free Acids % dry wt. $\times 10^{-1}$	Soluble Solids % fresh wt. $\times 10^{-1}$
1	95	15.4	352	190	130	60	231	120
2	100	16.0	341	160	123	37	279	121
3	108	16.4	360	170	124	46	247	128
4	103	14.4	334	151	118	33	231	111
5	102	15.4	374	186	134	52	266	117
6	102	17.4	401	151	115	36	272	131
7	104	15.8	389	194	140	54	172	126
8	96	15.7	372	141	110	31	204	123
9	89	15.2	330	163	125	38	237	116
10	78	16.1	365	181	138	43	234	128
11	93	16.3	387	165	127	38	235	125
12	93	17.1	362	143	109	34	241	132
13	81	15.4	372	159	119	40	190	124
14	94	16.1	393	164	123	41	262	128
15	105	16.9	354	132	103	29	259	132
16	97	16.3	367	167	121	46	233	122
17	89	16.5	426	157	119	38	243	131
18	80	16.5	369	190	136	54	252	128
19	92	16.5	401	206	138	68	249	129
20	88	16.3	322	155	124	31	226	127
21	93	17.8	376	147	114	33	233	-
22	87	16.2	362	140	115	25	243	124
23	106	16.5	356	176	130	46	273	130
24	119	18.0	333	101	88	13	368	141
25	84	16.6	366	201	136	65	224	127
26	98	15.6	384	164	123	41	220	124
27	103	15.4	381	168	127	41	243	123
28	86	15.7	369	179	133	46	240	122
29	102	15.0	379	217	142	75	300	119
30	110	14.9	343	146	115	31	162	117
31	125	15.2	393	171	118	53	295	120
32	121	16.9	401	178	125	53	237	135
33	109	15.8	383	207	138	69	270	124
34	100	16.0	305	179	130	49	256	129
35	89	17.7	363	175	129	46	248	137
36	90	15.5	316	177	131	46	195	123
37	89	16.0	397	155	117	38	266	130
38	83	16.0	353	185	132	53	273	130
39	100	15.8	246	180	126	54	288	126

TABLE VII. STATISTICAL DATA : CORRELATIONS OF VARIABLES

Correlation	Site or area	Year	No. of observations	Correlation coefficient r	% level of Significance of r	Regression coefficient
Cell volume and mean fruit weight	X	1954	39	0.7204	1	2.302
		1955	39	0.6536	1	1.309
	A,B,C	1954	32	0.6816	1	0.422
		1955	19	0.6329	1	1.346
		1956	44	0.7483	1	1.999
Protein nitrogen and soluble nitrogen	X	1954	39	0.8299	1	1.082
		1955	39	0.6538	1	0.636
		1956	39	0.8302	1	0.966
	A,B,C	1954	30	0.7908	1	1.063
		1955	20	0.9300	1	0.882
		1956	44	0.8200	1	1.514
Protein N/cell and cell volume	X	1954	39	0.8078	1	1.787
		1955	39	0.3960	2	0.701
	A	1954	12	0.8599	1	1.960
	A,C	1956	32	0.6449	1	1.431
Protein N/unit cell surface and cell volume	X	1954	39	0.3947	2	0.080
		1955	39	-0.3742	5	-0.090
	B	1956	8	-0.7925	2	-0.520
Respiration/cell and cell volume	X	1955	39	0.7570	1	1.708
	A,B,C	1956	34	0.8117	1	0.501
Respiration/unit cell surface and cell volume	X	1955	39	0.4626	1	0.110
	A,B,C	1956	34	0.6587	1	0.326
R/P and cell volume	X	1955	39	0.6467	1	0.301
	A,B,C	1956	34	0.5961	1	0.580
Free acids and total nitrogen	X	1955	39	-0.4117	1	-0.774
	B,C	1956	16	0.7647	1	1.202
Soluble solids and cell volume	A,B,C	1956	44	0.7288	1	0.022
Soluble solids and mean fruit weight	A,B,C	1956	44	0.5495	1	0.045
Firmness and mean fruit weight	A	1954	12	0.7581	1	0.034
	B,C	1954	10	0.6889	5	0.053
	A	1956	20	0.6454	1	0.677
Breakdown and mean fruit weight	A	1954	12	0.8491	1	1.193
	B	1954	12	0.6427	5	0.090
	C	1954	8	0.8890	1	5.105
	X	1955	39	0.8012	1	0.914
	A,B,C	1955	18	0.5181	5	1.092
Rots and mean fruit weight	X	1954	39	0.3248	5	0.246
		1955	39	0.4553	1	0.438
	A	1954	12	0.8635	1	1.406
	B	1954	12	0.6669	2	0.550
	C	1954	8	0.8617	1	2.419
	A,B,C	1955	19	0.4743	5	0.405
	A,C	1956	32	0.7040	1	0.750
Deep scald and mean fruit weight	A	1956	7	0.8769	1	0.936
Jonathan spot and mean fruit weight	A,C	1956	32	0.7497	1	1.598

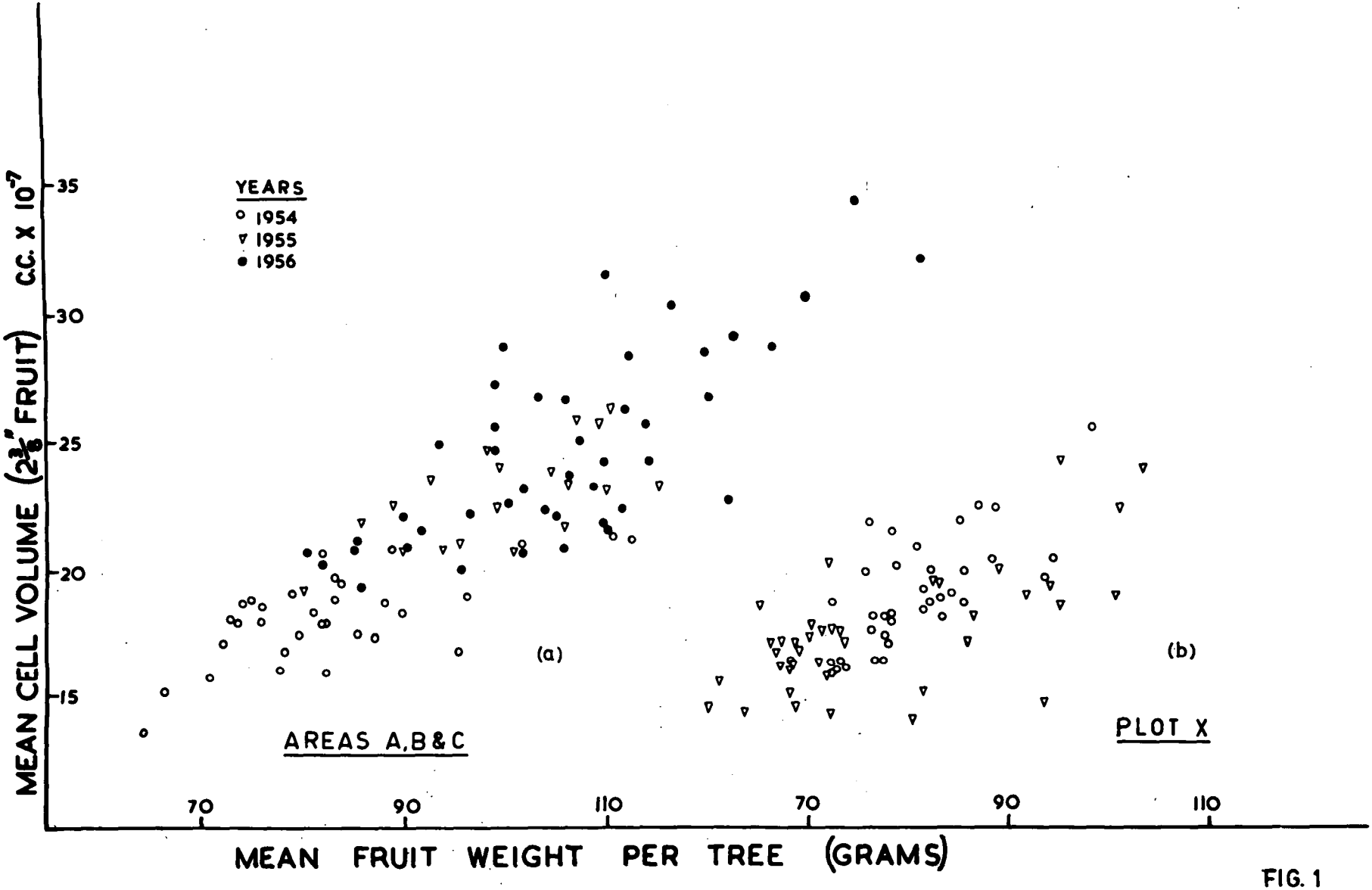

YEARS
1954
1955
1956
MEAN CELL VOLUME (2 1/8" FRUIT) C.C. X 10⁻⁷
35
30
25
20
15
(a)
(b)
AREAS A,B&C
PLOT X
70
90
110
70
90
110
MEAN FRUIT WEIGHT PER TREE (GRAMS)

FIG. 1

FIG. 2

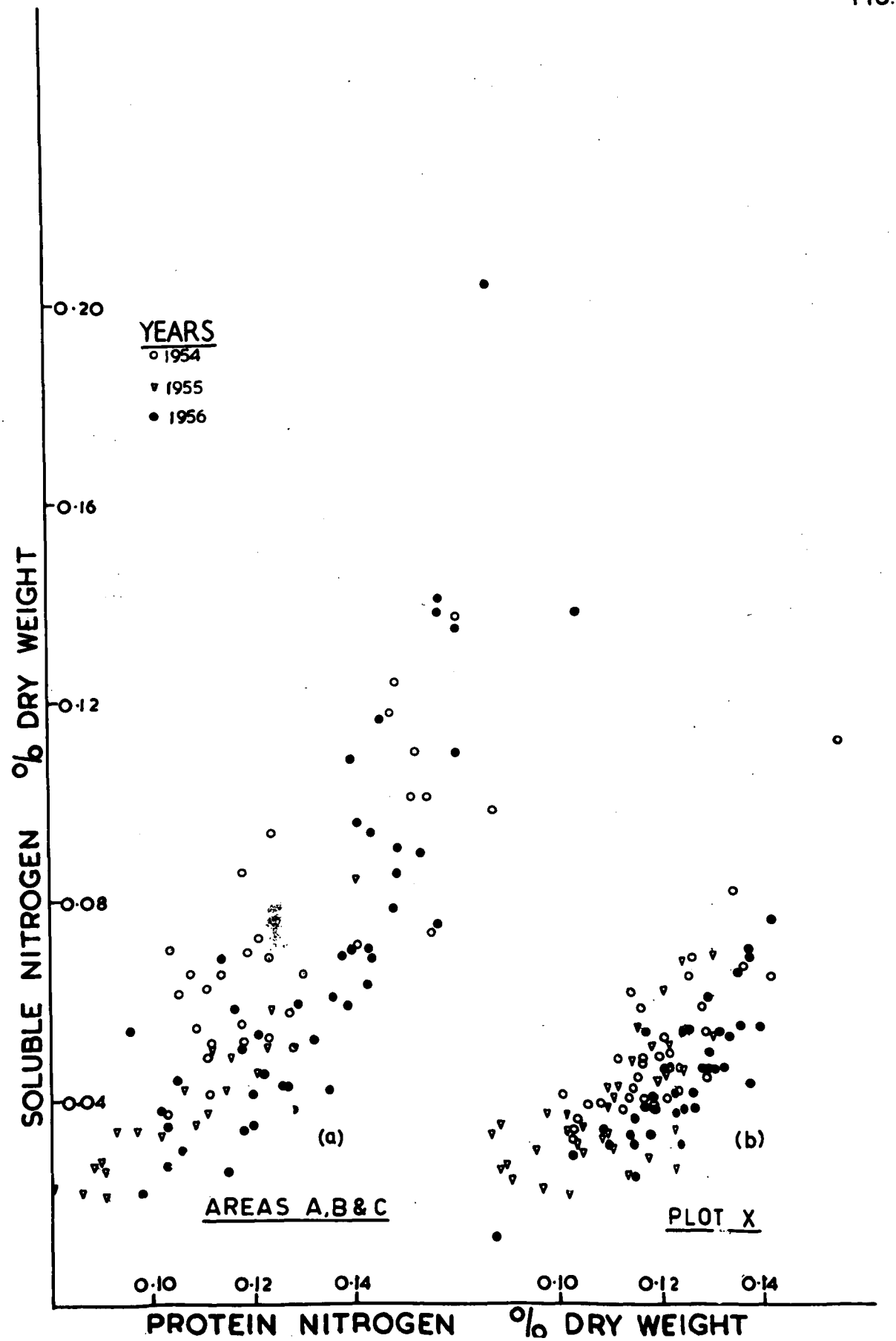

YEARS
1954
1955
1956
0·20
0·16
0·12
0·08
0·04
SOLUBLE NITROGEN % DRY WEIGHT
(a)
(b)
AREAS A,B&C
PLOT X
0·10
0·12
0·14
0·10
0·12
0·14
PROTEIN NITROGEN % DRY WEIGHT

FIG. 3

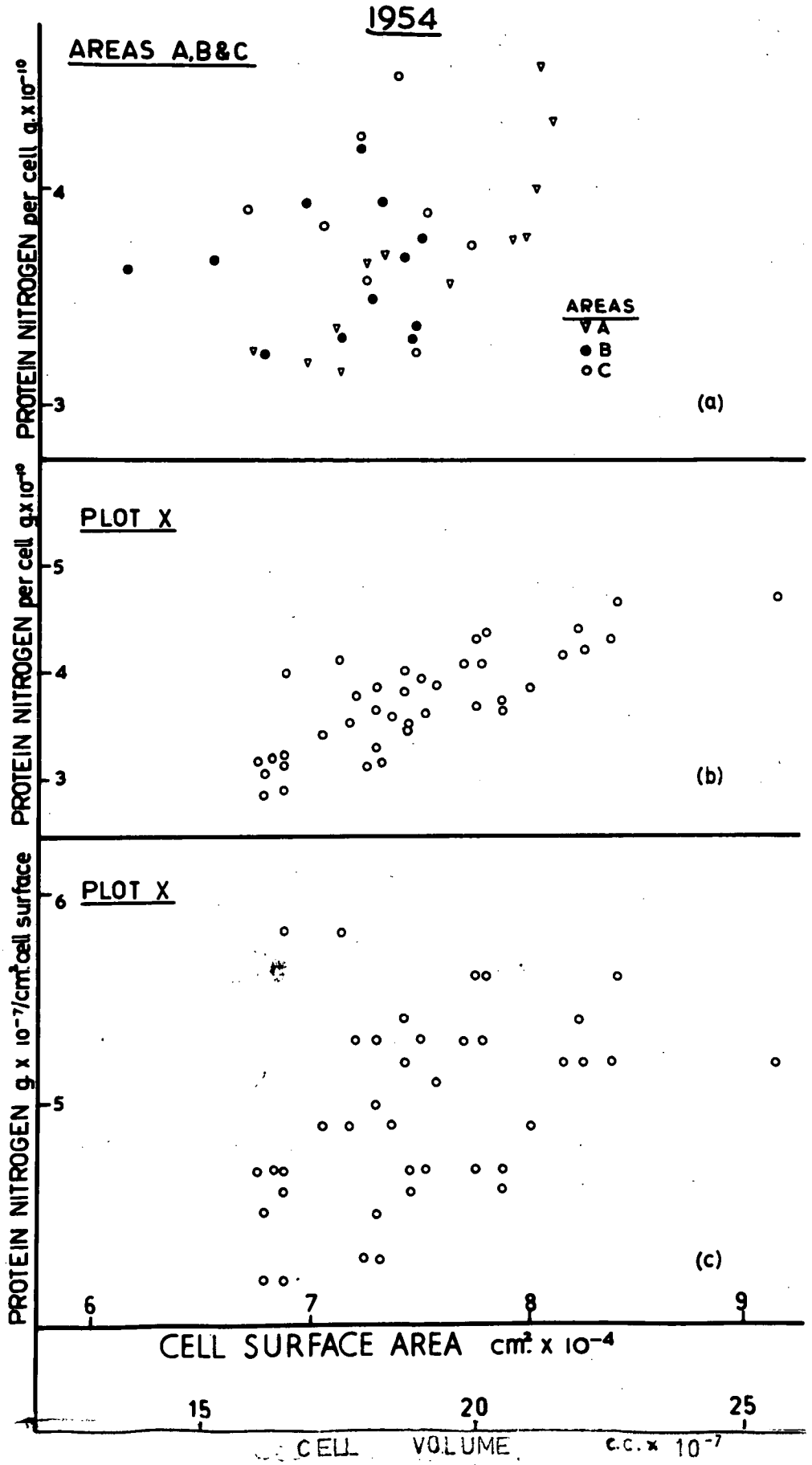
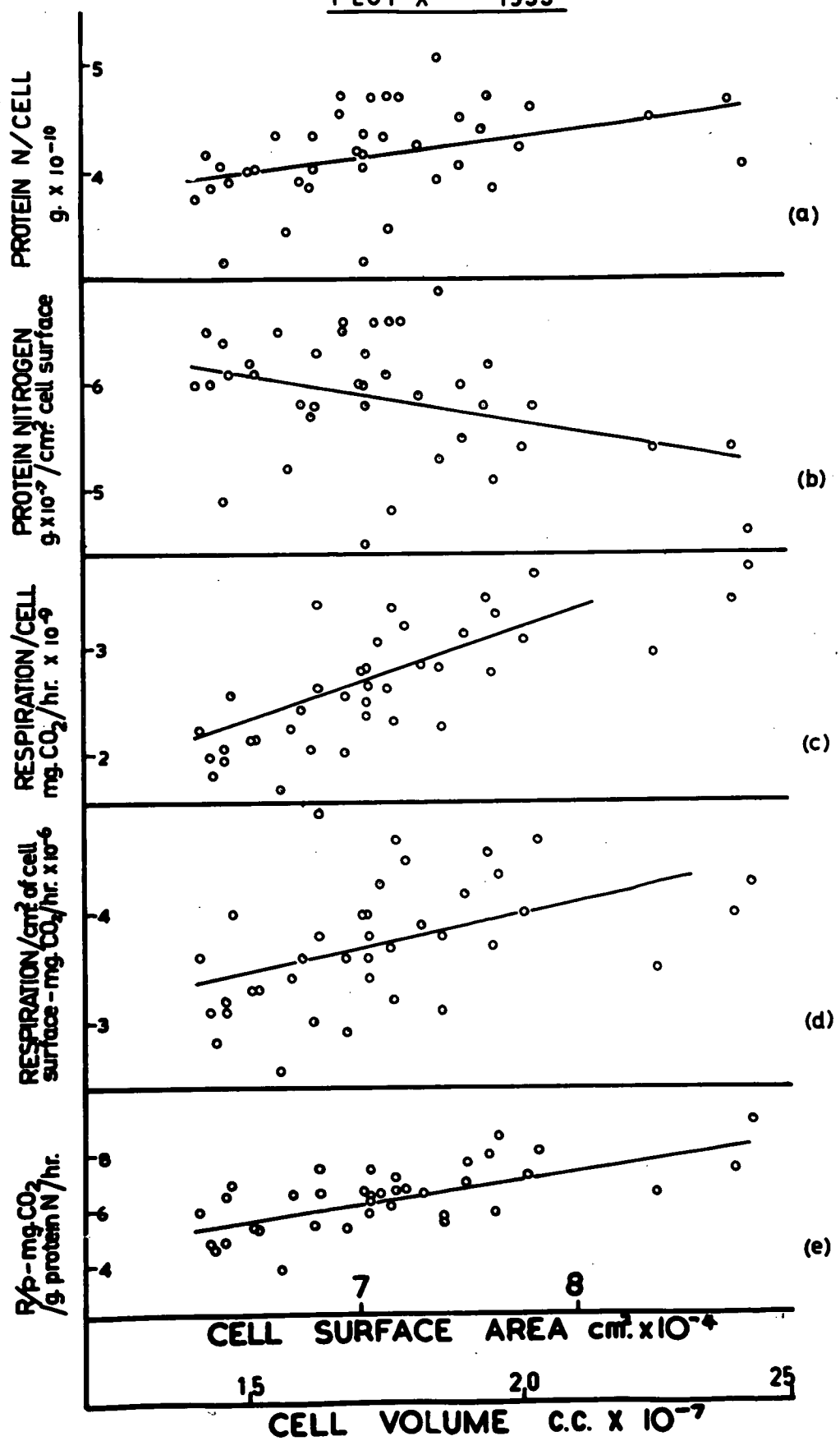

1954
AREAS A,B&C
PROTEIN NITROGEN per cell g.x 10⁻¹⁰
4
3
AREAS
A
B
C
(a)
PLOT X
PROTEIN NITROGEN per cell g.x 10⁻¹⁰
5
4
3
(b)
PLOT X
PROTEIN NITROGEN g x 10⁻⁷/cm² cell surface
6
5
(c)
6
7
8
9
CELL SURFACE AREA cm² x 10⁻⁴
15
20
25
CELL VOLUME c.c. x 10⁻⁷

FIG. 4


PLOT X 1955
PROTEIN N/CELL g. x 10⁻¹⁰
5
4
(a)
PROTEIN NITROGEN g.x10⁻⁹/cm² cell surface
6
5
(b)
RESPIRATION/CELL mg. CO₂/hr. x 10⁻⁹
3
2
(c)
RESPIRATION/cm² of cell surface - mg. CO₂/hr. x 10⁻⁶
4
3
(d)
R/P - mg. CO₂ /g protein N/hr.
8
6
4
(e)
7
8
CELL SURFACE AREA cm². x 10⁻⁴
1.5
2.0
2.5
CELL VOLUME c.c. x 10⁻⁷

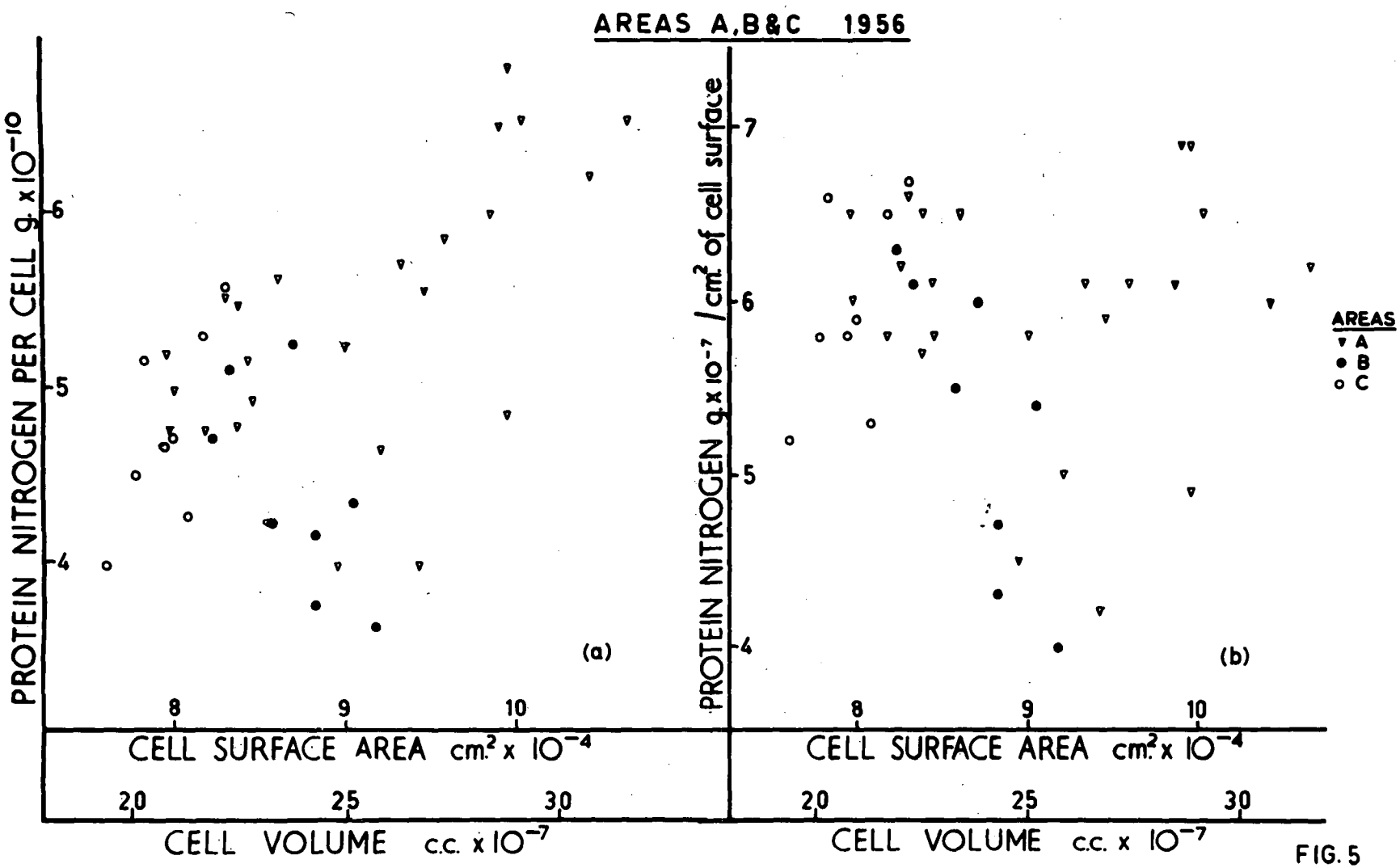
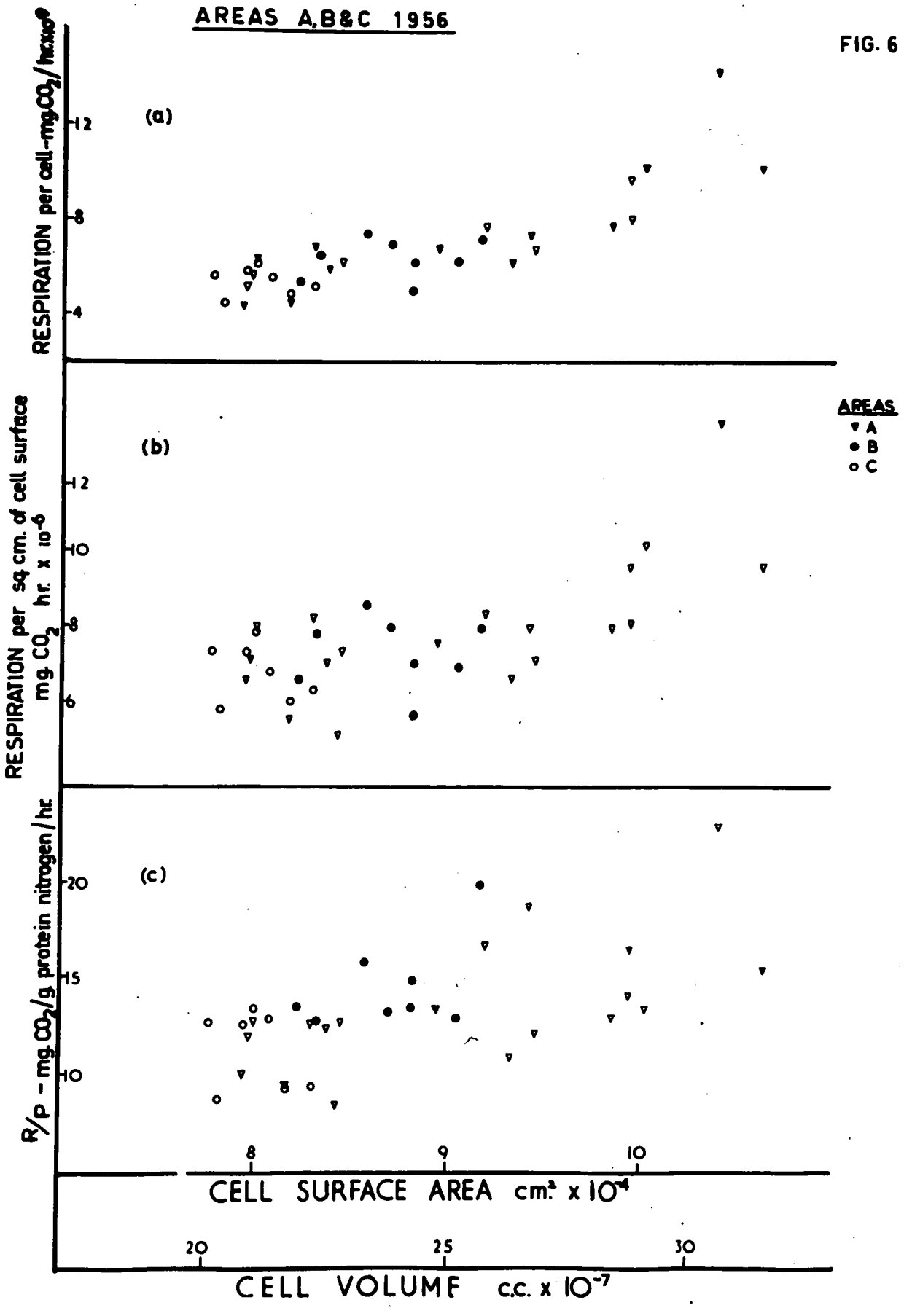

AREAS A,B&C 1956
PROTEIN NITROGEN PER CELL q x 10⁻¹⁰
PROTEIN NITROGEN q x 10⁻⁷ /cm² of cell surface
(a)
(b)
CELL SURFACE AREA cm² x 10⁻⁴
CELL VOLUME c.c. x 10⁻⁷
AREAS
A
B
C

FIG. 5


AREAS A,B&C 1956
FIG. 6
(a)
RESPIRATION per cell-mg.CO2/hr.x10^6
12
8
4
(b)
RESPIRATION per sq cm. of cell surface
mg. CO2 hr. x 10^-6
12
10
8
6
AREAS
A
B
C
(c)
R/P - mg.CO2/g protein nitrogen/hr.
20
15
10
8
9
10
CELL SURFACE AREA cm² x 10^-4
20
25
30
CELL VOLUME c.c. x 10^-7

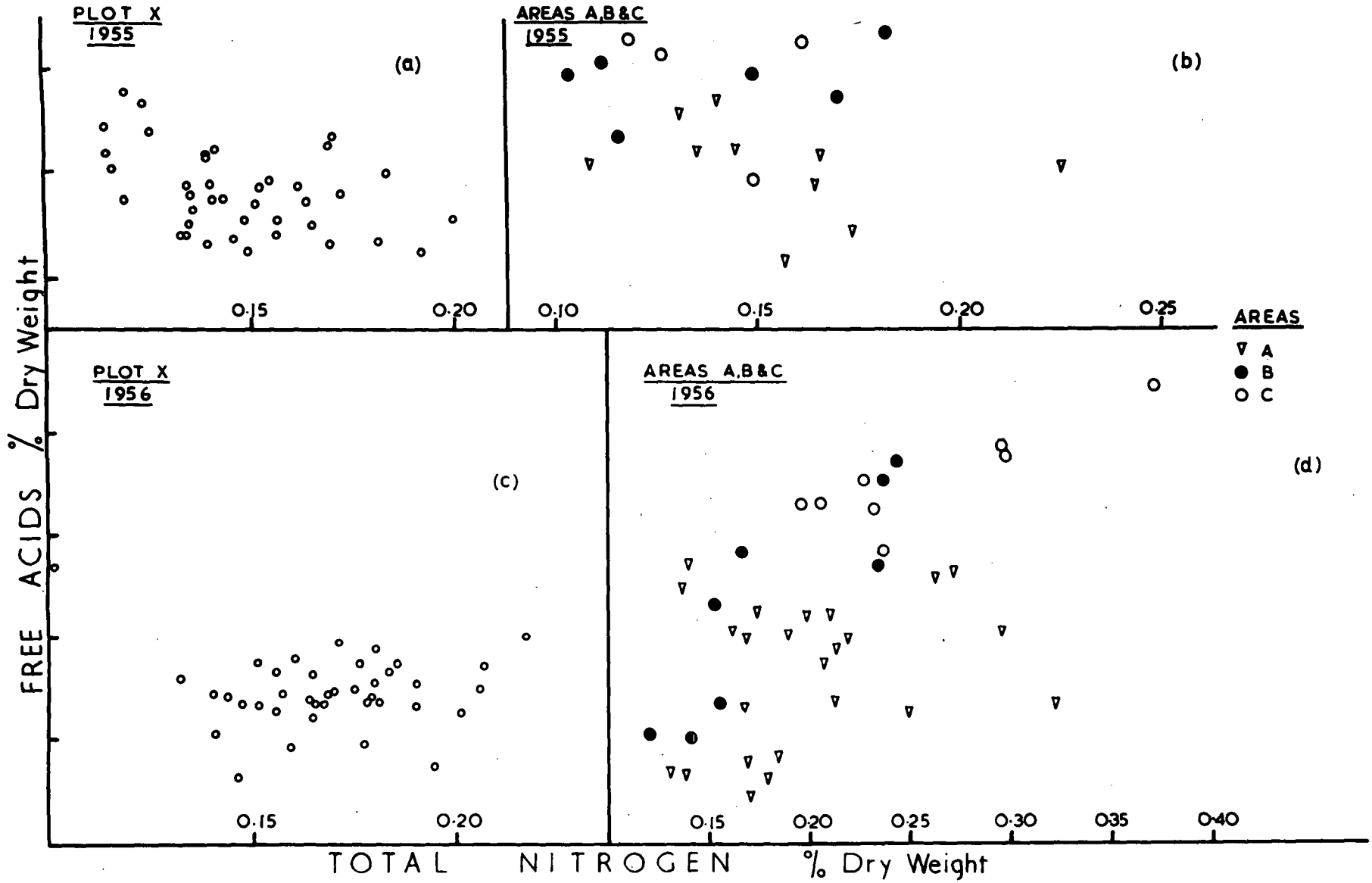

PLOT X
1955
(a)
0·15
0·20
AREAS A,B&C
1955
(b)
0·10
0·15
0·20
0·25
AREAS
A
B
C
PLOT X
1956
(c)
0·15
0·20
AREAS A,B&C
1956
(d)
0·15
0·20
0·25
0·30
0·35
0·40
FREE ACIDS % Dry Weight
TOTAL NITROGEN % Dry Weight

FIG. 7

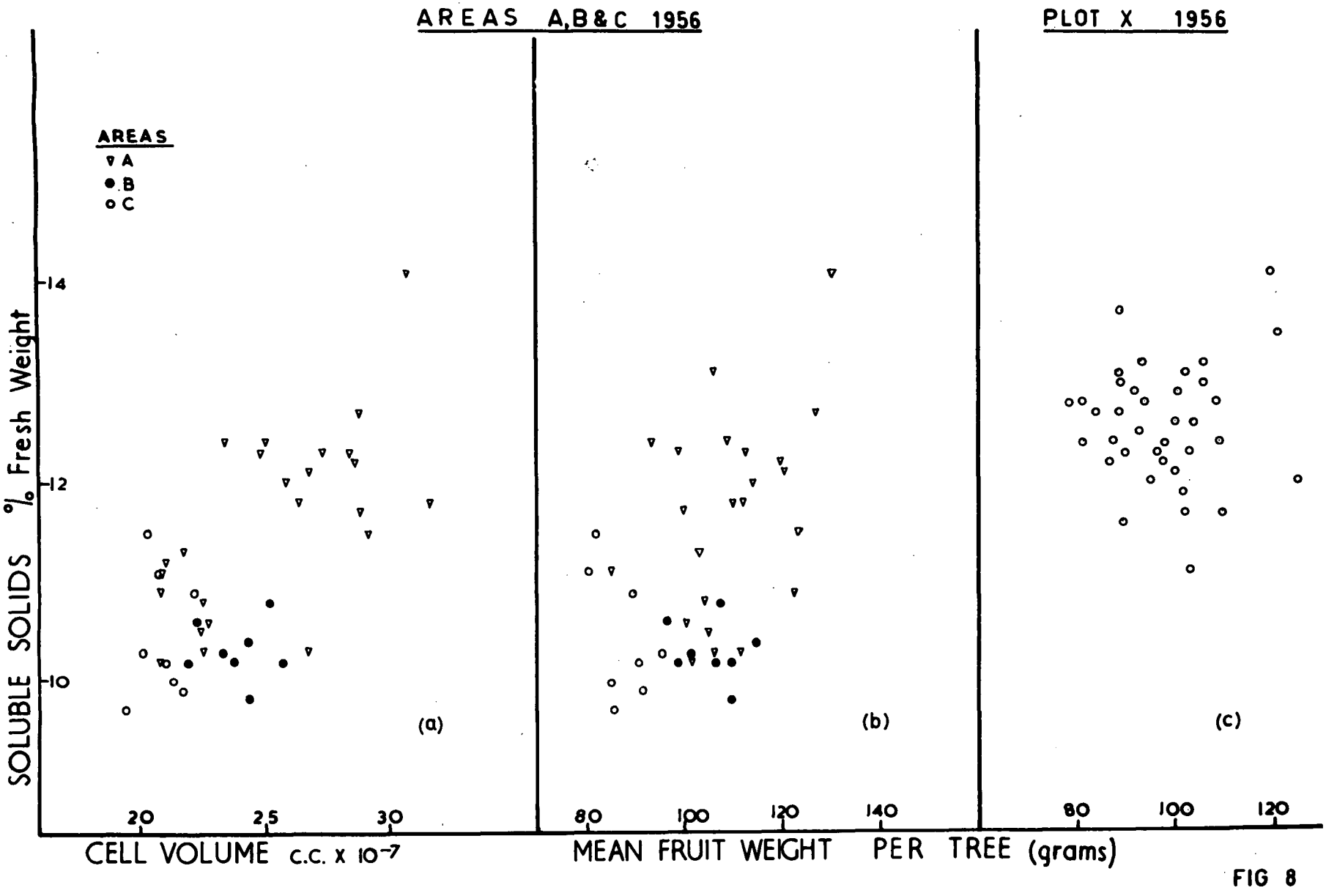
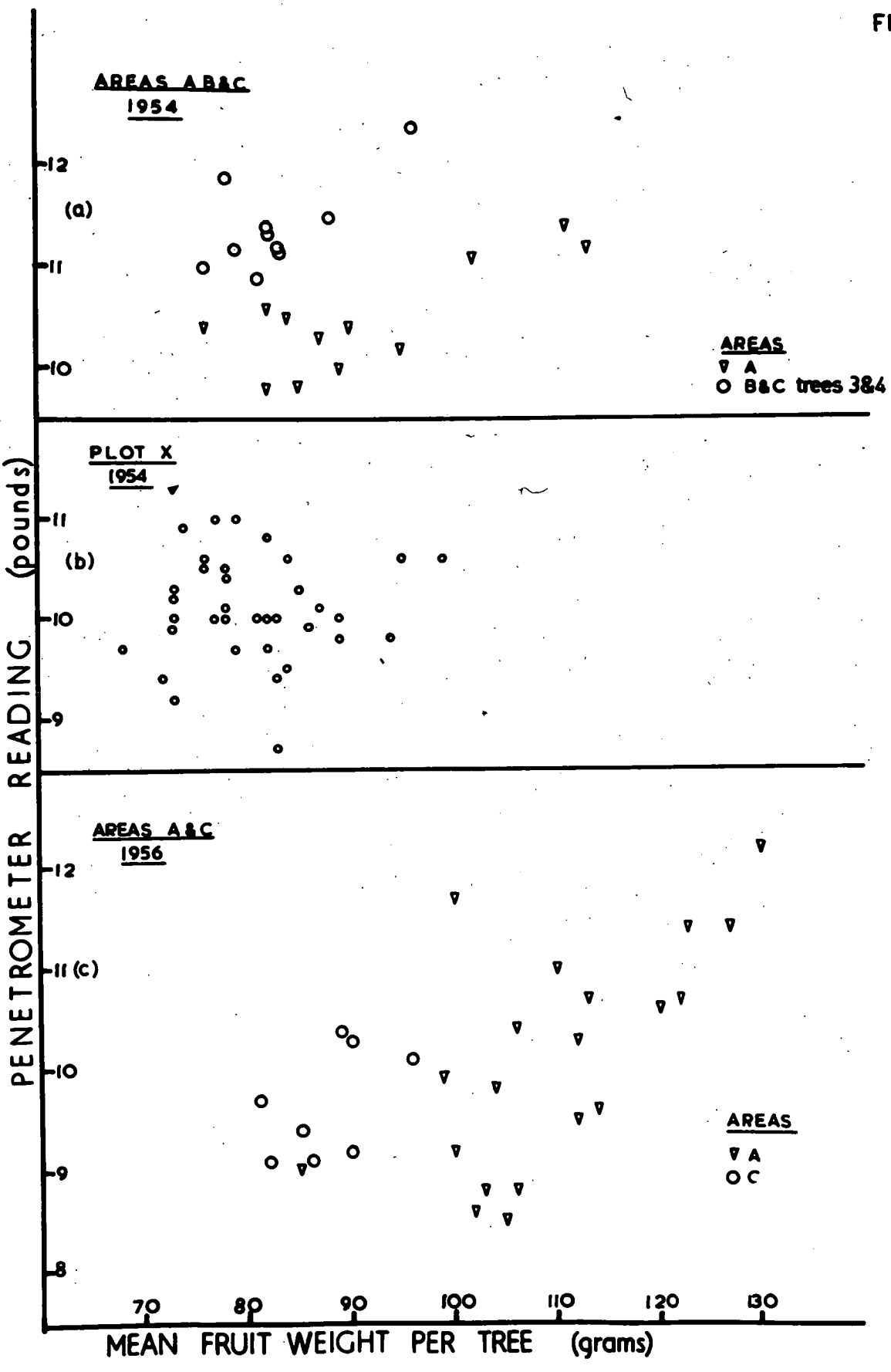

AREAS A,B&C 1956
PLOT X 1956
AREAS
A
B
C
SOLUBLE SOLIDS % Fresh Weight
14
12
10
(a)
(b)
(c)
20
25
30
80
100
120
140
80
100
120
CELL VOLUME c.c. x 10⁻⁷
MEAN FRUIT WEIGHT PER TREE (grams)

FIG 8

FIG. 9


AREAS A B&C
1954
(a)
12
11
10
AREAS
A
B&C trees 3&4
PLOT X
1954
(b)
11
10
9
AREAS A&C
1956
12
11 (c)
10
9
8
AREAS
A
C
PENETROMETER READING (pounds)
70
80
90
100
110
120
130
MEAN FRUIT WEIGHT PER TREE (grams)

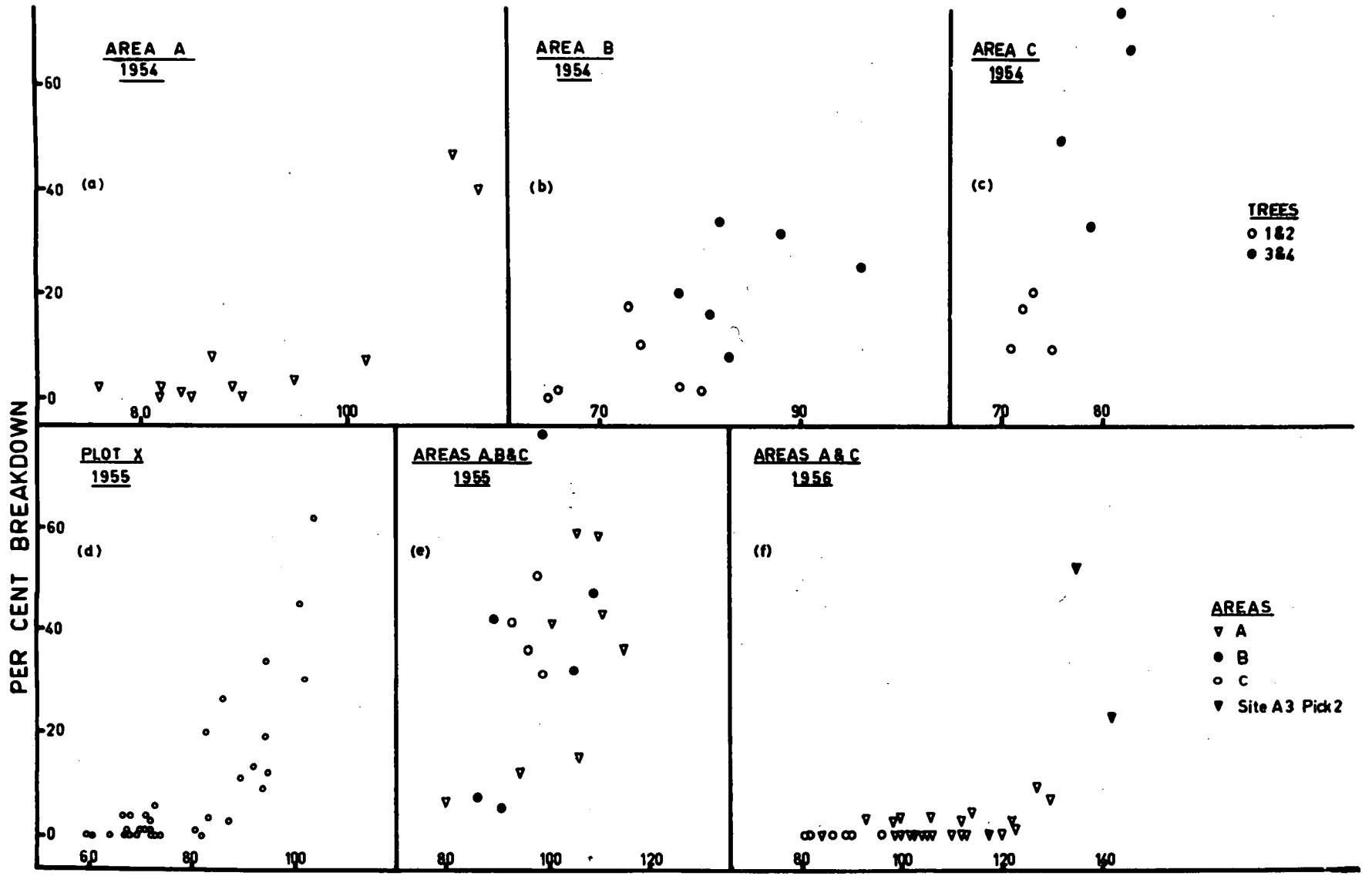

AREA A
1954
(a)
AREA B
1954
(b)
AREA C
1954
(c)
TREES
1&2
3&4
PLOT X
1955
(d)
AREAS A,B&C
1955
(e)
AREAS A&C
1956
(f)
AREAS
A
B
C
Site A3 Pick2
PER CENT BREAKDOWN
MEAN FRUIT WEIGHT PER TREE (grams)

FIG. 10

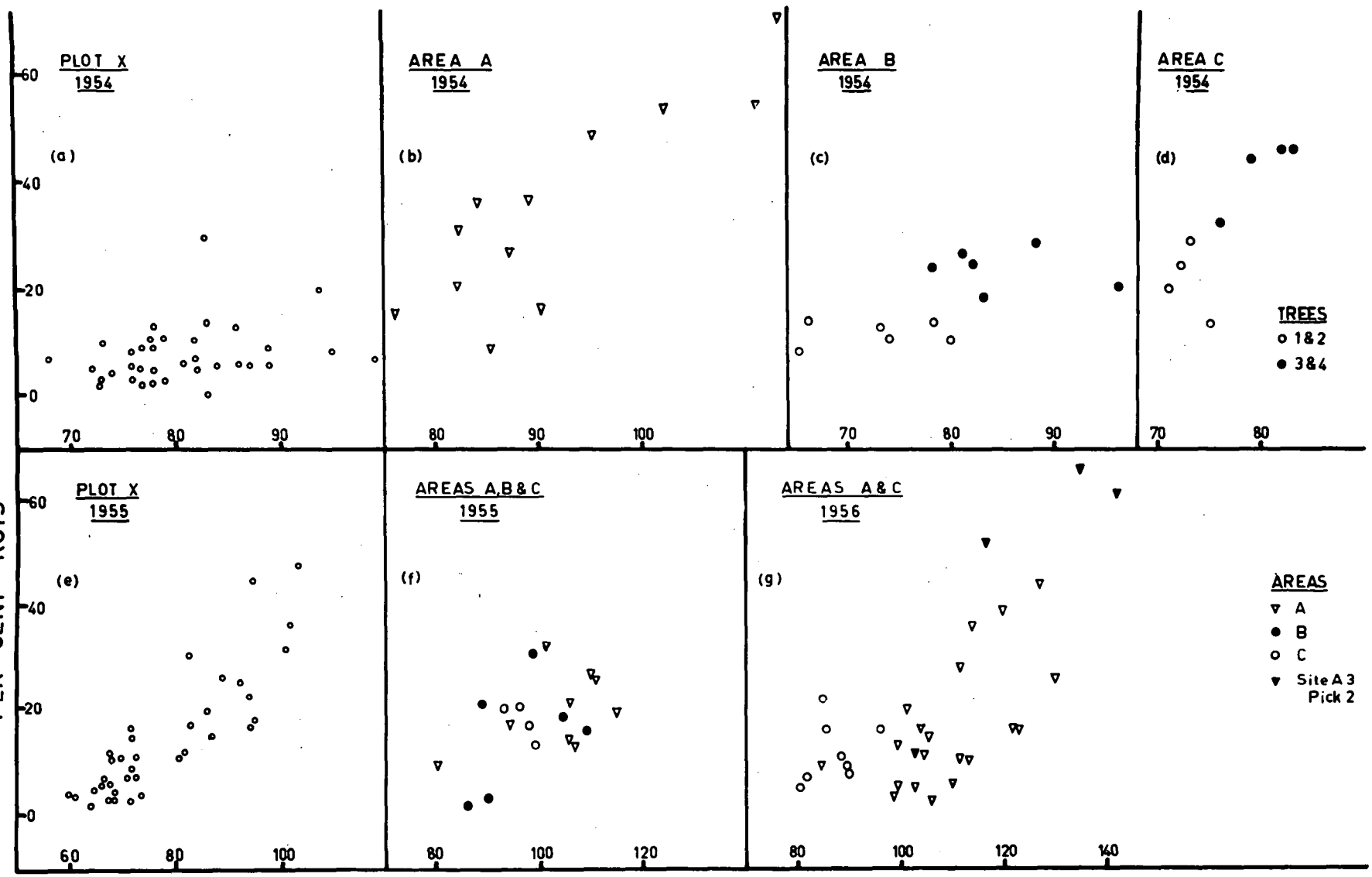
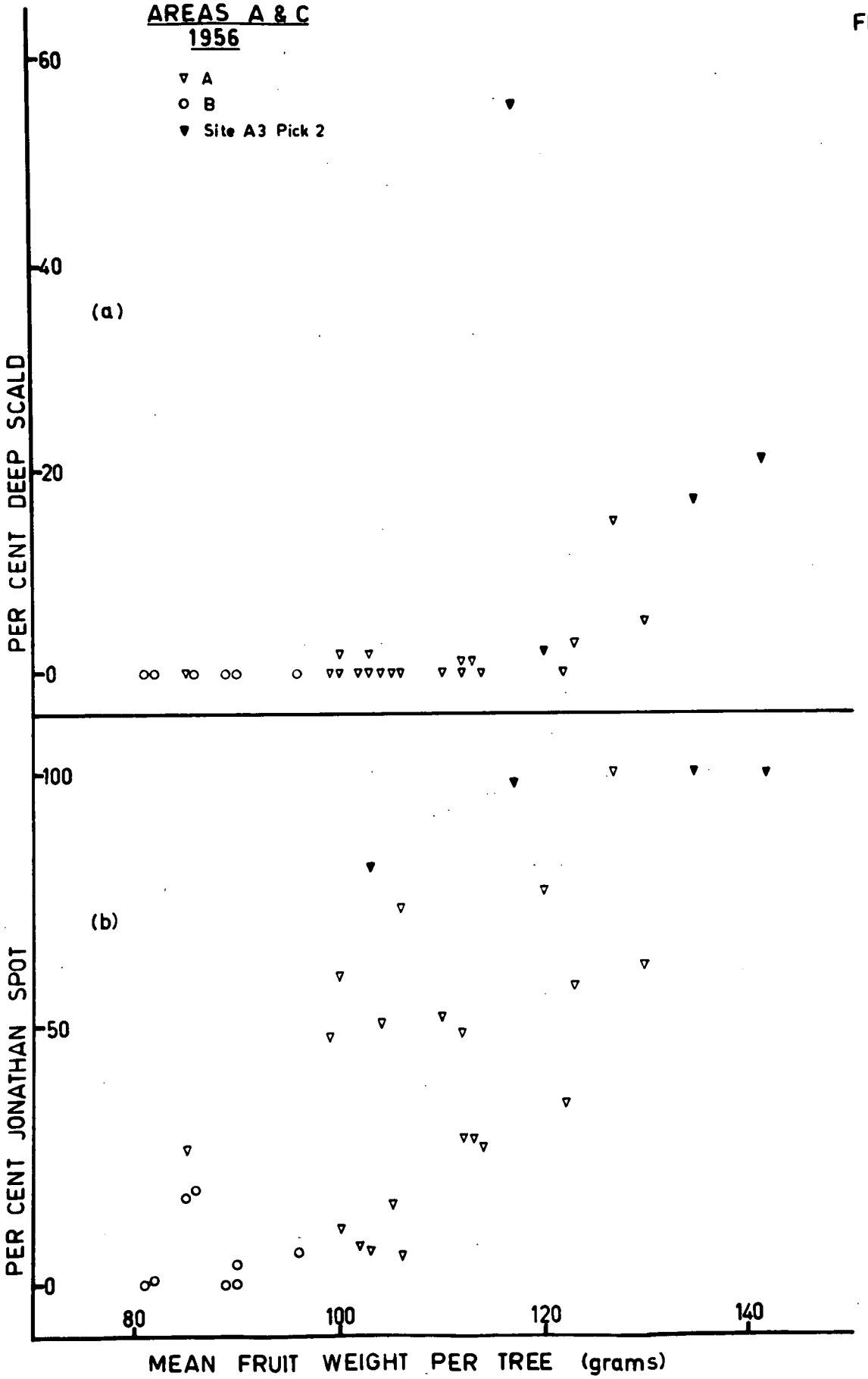

PLOT X
1954
(a)
AREA A
1954
(b)
AREA B
1954
(c)
AREA C
1954
(d)
TREES
1&2
3&4
PLOT X
1955
(e)
AREAS A,B&C
1955
(f)
AREAS A&C
1956
(g)
AREAS
A
B
C
Site A 3
Pick 2
PER CENT ROTS
MEAN FRUIT WEIGHT PER TREE (grams)

FIG. 11

FIG. 12


AREAS A & C
1956
A
B
Site A3 Pick 2
(a)
PER CENT DEEP SCALD
60
40
20
0
(b)
PER CENT JONATHAN SPOT
100
50
0
80
100
120
140
MEAN FRUIT WEIGHT PER TREE (grams)

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